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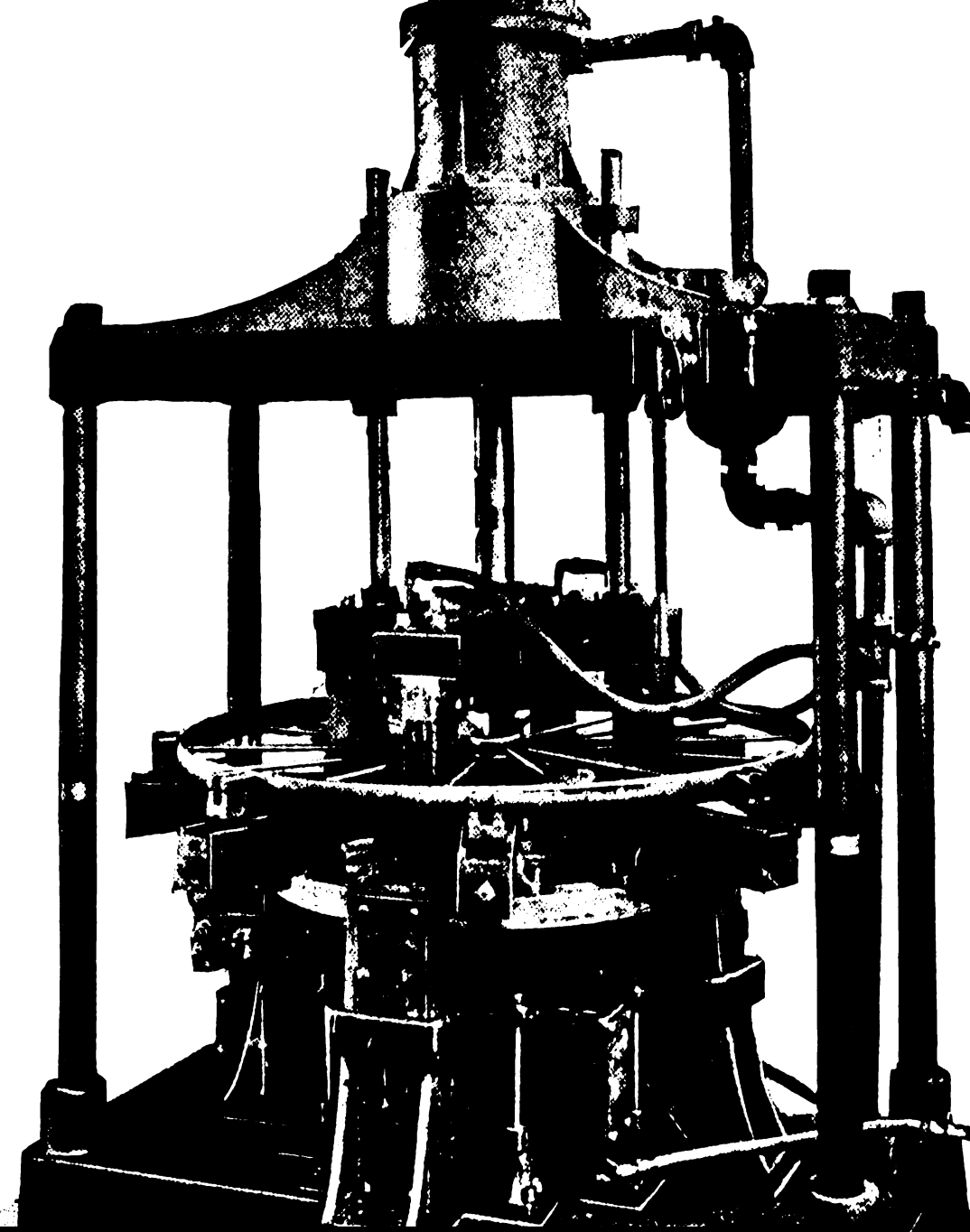

Welding

Richard Newell Hart

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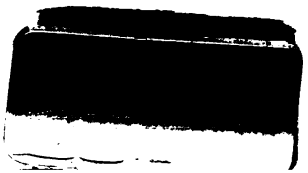

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WELDING

THEORY, PRACTICE, APPARATUS AND TESTS

ELECTRIC, THERMIT AND HOT-FLAME PROCESSES

BY

RICHARD N. HART, B. S.

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PREFACE

In spite of the numerous data on the theory, practice, apparatus, and tests of welding contained in the trade journals and metallurgical books, no previous attempt has been made to present this data in sequence under one cover. But in the last fifteen years the subject has begun to be of interest and importance. The electric, thermit, and hot-flame processes are welding all of the metals and are doing *repeat* and *repair* work that has never before been attempted. New brazing methods have also been successfully tried out and the range of good solders greatly increased.

I have given separate chapters to the commercial metals. Few of the metallurgies give much space to the working properties of the metals, especially the welding property, which is often merely mentioned.

Test and cost data must be taken with a grain of salt. The test data have been compiled from various sources. Those tests given for iron are standard and cannot be questioned. Those tests given for the special processes are more recent and in most cases have been made by interested parties. They are no doubt accurate, but at present the special processes cannot be so well represented by test data, as by the actual work they turn out. The same may be said of cost data. The prospective purchaser of welding machinery must figure the cost of his apparatus plus the cost of labor and the depreciation. But above all, he must satisfy himself that the apparatus he chooses is the best for his kind of welding.

I wish to express my thanks for assistance received from the different welding companies mentioned herein; also to James H. DeLong, for special analyses; Dr. Edward Hart, Dr. Joseph W. Richards, Prof. Oliver P. Watts, Otis Allen Kenyon, E. A. Colby, of Baker & Co., and to many others.

R. N. HART.

LOS ANGELES, CAL., *October*, 1910.

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DEFINITIONS AND INTRODUCTION

According to the Standard Dictionary, to *weld* is to "unite, as heated metal, in one piece or mass under the hammer or by pressure."

The Century Dictionary says, "To unite or consolidate, as pieces of metal or metallic powder, by hammering or compression, with or without previous softening by heat." * * * "term is more generally used when the junction of the pieces is effected without the actual fusing point of the metal having been reached." While the Standard adds, "Metals are weldable in proportion to the length of time they will stay under heat in a plastic condition without melting."

Welding is distinguished from soldering, which is, according to the Standard, "To unite, as two metallic substances, by solder." The Century, "To unite by a metallic cement." * * * "Every kind must be used as its own melting point, which must be always lower than that of the metals to be united."

I give these definitions because there is some confusion of the terms; and naturally so, as the two processes often are undistinguishable. Thus two unlike metals, as iron and platinum, may be welded; while a fractured steel bar may be united by placing platinum foil between the pieces, pressing strongly together and heating moderately. This is strictly welding, yet the platinum foil is solder. In the recent processes of welding by fusion, the molten metal becomes a solder. Brazing is classed as soldering, but when brass is brazed the process is as nearly welding as the so-called *autogenous* weld.

The word *autogenous* is misapplied to welding. It means *self-produced.* The melted weld of the oxy-hydrogen or acetylene flame is a soldering process in which the metal produces its own solder. However, it makes a catchy trade-name.

Welding, under different names, is a property possessed by many substances, both elemental and compound. According to

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Roberts-Austen,[1] who devotes considerable space to the *flowing* property of metals, "welding is the property possessed by metals, which on cooling from the molten state pass through a plastic stage before becoming perfectly solid, of being joined together by the cohesion of the molecules that is induced by the application of an extraneous force, such as hammering."

In general, welding occurs if cohesion between the molecules of the two pieces can be induced. This cohesion may amount to diffusion when the two pieces are of unlike substance, and the metal at the weld will be found to be an alloy of the two, Thus gold and lead, pressed together for several weeks, will weld at ordinary temperature. At 100 deg. C. they will weld in less time, and the weld will be an alloy of gold and lead.

Welding and diffusion are not inseparable, however. For the welding by diffusion of lead and gold is weaker than the first-named cold weld. While the diffusion of mercury through another metal invariably produces weakness of that metal, sometimes disintegration.

Regelation is the name given to the welding of two pieces of ice. Faraday is credited with this discovery. He found that two pieces of ice slightly below freezing point, if pressed together will weld. Wrightson[2] states that both iron and ice suffer a drop in temperature when pressed together. He heated two irons to the plastic state in an electric welder and pressed them together. The recording pyrometer showed a sudden fall of from 19 deg. to 57 deg. C. He further states that iron increased almost 7 per cent. in volume on becoming plastic, and tries to trace an analogy between the behavior of iron and ice. It has since been found that regelation is a property possessed in some degree by most crystalline substances. Pure crystalline salts will regelate under pressure at moderate temperature. Even such a substance as bismuth will regelate.

Evidently welding depends upon two things:

1. *The flow.*

Most of the so-called solids are fluid to some extent. Highly crystalline, refractory rocks will flow under great pressure. The

[1] "Introduction to Metallurgy," p. 47.
[2] *Journal of the Iron and Steel Institute*, 1895, Vol. I, p. 499.

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walls of some deep mines have flowed together in the course of time. A rod of glass or of sealing-wax will bend or flow if it supports a weight for several days. Lead, sodium, etc., flow readily under pressure.

Flow is almost synonymous with malleability, the difference being a matter of time. Many substances which flow slowly will not withstand the shock of the hammer.

Most metals flow at all temperatures from normal to melting point, but they are the most easily weldable within the range of greatest plasticity. But their welding also depends upon—

2. *The wetting* or cohesion of the two substances.

Two pieces of the same or different substance will not weld if their surfaces do not cohere, no matter how malleable or fluid they may be. Aluminum is a notable instance. The metal is quite malleable at most temperatures, but a microscopic film of oxid prevents the two surfaces from wetting one another. Iron in a lesser degree is troubled with a coating of oxid at welding temperature. Any flux which will clean off both surfaces will allow a weld to be made. In proportion to the ease with which one can have and hold a clean surface of the metals in the range of plasticity, in that proportion will welding be feasible. The welding of malleable metals is dependent on the behavior of the oxids which form on their surface. In proof of this is the remarkable experiment of Chernoff[1] in 1877. He showed that a partial weld of two pieces of iron could be made at the low temperature of 650 deg. C., which is at least 700 deg. below common welding heat. The two surfaces were planed and highly polished. Pressure was applied for several days, when it was found that there was a partial weld. This is similar to the well-known experiment in physics where two plane and highly polished surfaces of glass are pressed together. The surfaces will cohere to some extent.

These two experiments seem to show that whatever assists cohesion, assists the welding. There are numerous instances of welding among non-metallic substances which do not oxidize at the welding heat. Glass is too well-known to need explanation. Pieces of horn can be joined under pressure of hot plates if the horn be kept moist.

[1] *Revue Universalle des Mines*, Vol. I, 1877, p. 411.

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Metals newly nascent, in a fine powder, can be welded into a solid piece by a stroke of the hammer. Apparently for the reason that the grains of powder have bright, clean faces. Most of the malleable metals are so weldable.

THEORIES OF WELDING

In 1877, Holley[1] advanced the theory that irons weld in proportion to their mobility or flowing, and inversely as oxidation of the welding surfaces occurs. He thought that the more plastic or more nearly melting point the irons were, the more readily they would weld. But with every increase in heat was a corresponding readiness to oxidize—especially on the part of carbon and iron. This oxid interposed a mechanical difficulty to perfect welding.

This theory does not satisfy Campbell[2] who insists that impurities tend to crystallization in the body of the iron. Carbon, which is the principal offender, and sulphur, phosphorus, and other ingredients, all form alloys or compounds with the pure ferrite. Ferrite itself is exceedingly malleable and mobile. But a mixture of ferrite and several of the carbon compounds, as cementite, martensite, etc., is stiff above red heat in proportion to the carbon present. Campbell thinks that such a steel, which is really a mineral with a granitic structure, will not weld, because it refuses to flow. He claims that oxidation troubles are actually less, because the chemical combination of the iron oxid with the impurities and their oxids would give a self-fluxing surface.

According to Campbell, then, those impurities which caused decided crystallization with accompanying brittleness, interfered with the flow at high heat and prevented welding. Manganese, it is true, makes a more brittle iron, up to 1.20 per cent; but it prevents crystallization of sulphur, etc., and is an aid in welding.

For ordinary and commercial purposes the welding must be done in a few seconds' time, and the previous cleaning and heating must not take long. This at once limits to a very few the number of metals which can be welded; were it not for the recent

[1] *Trans. American Institute of Mining Engineers*, Vol. VI, p. 112.
[2] "Metallurgy of Iron and Steel," p. 589.

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remarkable advance due to the electric, oxy-hydrogen and acetylene processes of melting, welding would be confined to iron, platinum, nickel, and gold. Other metals would be joined by soldering and brazing, and even then the metal worker would have great difficulties with aluminum and many alloys.

I will first take up iron and steel welding. As much research work has been done on the metallurgy of iron as on all of the other metals combined. It is extremely probable that many of the difficulties and problems arising from proportions of impurities and methods of producing will apply equally to other metals. For this reason, and because of its overwhelming importance, I will treat of iron more thoroughly.

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WELDING

PART I—THE METALS

IRON

Pure or nearly pure iron is readily weldable at a white heat. Malleable, or nearly pure wrought iron, is known as *weld iron.* The range of temperature in which it can be welded is very wide: it runs from the imperfect weld at cherry-red, to dazzling white, when the welding property is lost just before the iron melts. According to Pouillet, the different colors of heated metals are represented approximately by the temperatures given:

	Deg. C
Incipient red	525
Dark red	700
Incipient cherry	800
Clear cherry-red	1000
White	1300
Dazzling white	1500
Melting	1550

Wrightson[1] states that he found iron to increase in volume as much as 7 per cent. when passing into the plastic stage.

Malleable Iron.—*Weld iron* is a name occasionally used to describe malleable iron, indicating that it is pure enough to be welded. Malleable iron is produced by the puddling process. It is made by melting up pig iron and scrap in an open-hearth furnace and burning out the greater part of the silicon, manganese, and carbon in the order named. As the burning continues the melting point of the iron rises, and it becomes a pasty mass permeated with slag from the stirring. This nearly pure iron is gathered into "puddle balls," and taken to the rolls at a white heat. It is rolled or hammered out into long strips, the strips are cut, reheated to white heat, and welded together between the rolls or beneath the hammer. To produce the finest wrought

[1] *Journal of the Iron and Steel Institute,* 1895, Vol. I, p. 463.

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iron, the process of rolling and welding is repeated. This is the puddling process in brief; its object is to squeeze and work the slag out of the iron and to give the iron a fibrous structure like rolled copper.

The principal chemical difference between wrought iron and steel is the carbon content. In fact, except for its high carbon, basic open-hearth steel is purer than most malleable irons.

All weldable iron is not malleable, but it is weldable in proportion to its malleability. As is seen in the foregoing process, the iron is welded several times.

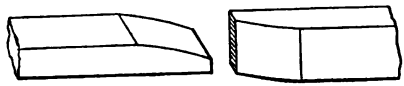

FIG. 1.—Views of scarfed bars for lap welding.

How to Weld Iron.—The mechanics of a "smithed" weld is in the main as follows: Suppose the smith wishes to join two short bars of malleable iron, of cross-section 1 by 2 inches. He first hammers or cuts a convex bevel or "scarf" on the ends of each bar, as shown in Fig. 1.

The heating must be done in a coke or coal forge. Coke is the best fuel for the reason that it gives a good reducing flame. The fire is blown with the bellows until it is at a high heat. The ends of the bars are thrust well into the midst of the ignited coke and more coke is piled over them. The blowing is continued until the bars are red-hot on the ends, when the smith takes them out with pliers and dips them into pure sand or borax near by. This is the flux, and it so acts on the surface of the iron as to clean it of rust and forms a glass that protects the fresh iron from further rust. The smith puts his irons back into the forge again and heats them until white.

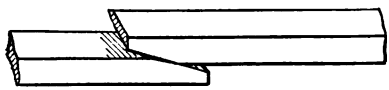

FIG. 2.—Bars in position for lap welding.

When white, or nearly white-hot, the smith takes one bar in his pliers, his helper takes the other, and they place them together on the anvil, the one lapping the other (Fig. 2). Both the smith and his helper give the pieces quick, light blows with their hammers until the plastic iron is well-joined. They turn the irons while hammering to get an even weld on all sides.

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The smith will try to weld at a white, but not a dazzling white, heat, and he will try to complete it without putting it back into the fire for a reheating.

When the weld is finished, he may give it a special shape by placing it between swage blocks and hammering.

This simple operation of welding requires much skill, as will appear. The smith may find that with all his skill his joint is bad or that his iron will not join at all.

Points in Practice.—In practice there are the usual number of details requiring skill that the smith must observe.

The contact faces should always be shaped so that their middle points touch first and so that hammering causes union first at the middle. This prevents slag becoming enclosed.

The heating should be done rather slowly, so that the pieces will be of uniform heat at the weld. Both irons should be of the same temperature. To effect this the smith must not blow up his fire too hot and must watch the color of both irons. A deep bed of coals will give a flame the least oxidizing, because most of the oxygen will burn to carbon monoxid or dioxid.

The welding heat is quite different for different irons. The smith must use his judgment, taking good care he does not overheat his irons. Overheated iron, miscalled "burnt iron," will be brittle on cooling. Steel is much more sensitive to overheating than iron. It is seldom safe to heat steel above redness.

The iron should be well fluxed directly on the contact surfaces, and not merely around them, as is too often the case. The common fluxes for iron are pure silica (river sand) and borax. Impure malleable irons are self-fluxing to a certain degree, but this cannot be relied on. Other fluxes are calcined borax and sal ammoniac. One writer[1] recommends powdered marble, which is limestone, the flux of the blast furnace. Borax is recommended for steel on steel or steel on iron, as silica is inadequate.[2] Besides fluxing the bars before raising them to welding heat, the smith may sprinkle calcined borax on the irons when they are ready to weld, to replace it on surfaces accidentally rubbed bare in the forge.

[1] "The Blacksmith's Guide," J. S. Sallows.
[2] "Testing of Materials of Construction," W. C. Unwin, 1899, p. 292.

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The hammering, or "working," is very important, and must be done rapidly. The smith manipulates his bars so that welding begins at a middle point and works outward, driving the slag away from it. The first few blows of the hammer should not be heavy. If the pieces are large or the smith slow, his heat will fall before the weld is finished and he must put his bars back in the fire. Second heating must be avoided if possible; slag is apt to

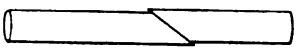

FIG. 3.—Lap weld. No upset.

FIG. 4.—Lap weld. Upset.

get in the weld or the pieces may become "burnt," to say nothing of the time lost.

The different kinds of welds known to the smith—butt, lap, scarf, jump, cleft—are variations of simple welds. Illustrations of them and of how the stock should be shaped are given in figures 3 to 7. The method of hammering will suggest itself in each case. Jump and butt welds will have sufficient upset to work on, while scarf welds will not unless the pieces are jumped or over-lapped considerably.

Welding Fires, etc.—The ordinary fire used by the smith for

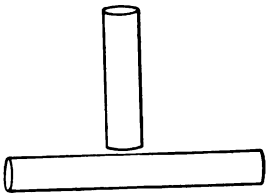

FIG. 5.—Jump weld.

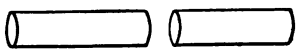

FIG. 6.—Butt weld.

his welding is a deep bed of coke. But the fire may be fed with hard or soft coal; it may also be a gas or oil flame.

For blacksmithing, the coke fire is much the best. In this fire nearly pure carbon is burned, and the resultant gases are carbon monoxid and dioxid. The carbon monoxid and the coke are reducing in their action. They will prevent the metal heated from oxidizing and will even clean the metal of scale.

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Hard coal can be used, but in a small forge it is impossible to get a hot enough fire. Soft coal is a poor coal for forge work. It has, as a rule, high sulphur, which the hot iron readily absorbs to its detriment. While the thick carbon smoke of the flame is apt to collect on the iron in an oily soot unless the flame can be kept hot enough.

Gas and oil flames are often used for chain welding and similar operations. The gas or oil should be fairly free from sulphur. The gas flame is made by injecting the gas through a large Bunsen burner. Air is introduced through holes in the burner a short distance from the burner end. Or if the gas is under sufficient pressure to make a roaring flame, it will take in enough air at the end of the burner. The proper mixture gives a nearly colorless flame. The quickest and best way to tell if a flame is right for welding is to heat in it a small piece of steel or soft iron. If the flame has too much air, the metal piece will rust and scale off in the flame. If too little air, the soot will collect on the metal and it will not heat quickly. Gas flame is the most convenient for most purposes. It is easy to regulate and can be turned on the iron while welding. In this way iron can be welded without flux. When chain is made the links are hung on a bar above a long narrow furnace of fire bricks. The flame is played beneath.

FIG. 7.—Cleft weld.

The oil flame is a cheaper flame than gas. It can be manipulated in the same way as a gas flame. But the oil must be free from sulphur compounds to make a safe flame.

It has lately been tried to burn gases that have been preheated. If coal gas, starting to burn at 35 deg. C., will give a combustion point of about 2000 deg., then by preheating it to about 800 deg. C. and burning, there will be a gain of 400 or 500 deg. in the temperature of the flame. In other words, the welder has boosted his flame up to about 2500 deg., a very respectable temperature.

The preheating is done by passing the gases through copper coils which are nested above the welding-flame flue, and which receive the heat from the welding flue.

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Causes of Poor Welds.—Suppose we have an iron or steel that will weld. There are still many good reasons for discrediting the safety of the joint until it has been tested. They are:

1. *Imperfect Contact.*

a. The two surfaces may give the appearance of perfect union, but a considerable percentage of the central portion may be faulty. For if the metal in course of puddling is not relieved of its enclosed slag, this will be finally pressed out into thin laminæ. These cleaving planes will be parallel with the bar until it is welded, when they will be upset in all directions at the joint. A network of such planes now running across the bar instead of parallel to it will greatly diminish the tensile strength.

b. Then, again, the smith may carelessly allow some of his flux to stay within the weld. All the hammering in the world

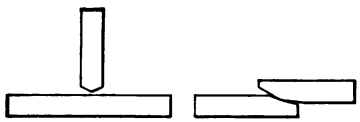

FIG. 8.—Correct shapes for jump and lap welds.

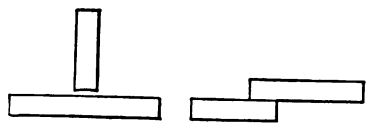

FIG. 9.—Incorrect shapes for jump and lap welds.

will not remedy it. In most cases one of the pieces can be scarfed or pointed, so that the first contact of the hot pieces will be at a central point. As the hammering proceeds, the slag will be forced out of the joint as fast as the pieces weld (see Fig. 2). This caution applies equally to the smithed weld or the Lafitte joint (see page 158).

c. Or the smith may not flux his bars correctly, thereby allowing unreduced and uncombined oxid of iron to get in the weld. It is not a difficult thing to get this rust incorporated in the weld, because it is soluble in iron. Dissolved rust makes a "burnt" or brittle joint. Clean silica sand is the common flux. The smith dips his hot bars into a box of the sand kept near by, and often sprinkles a handful over the pieces when hammering if the pieces are large. The reaction between the sand and the rust is rapid. Iron silicates, easily fusible, are formed. They

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cover the fresh iron surface with a thin glass, which prevents further oxidation.

2. *Insufficient hammering or "working"* may account for the poor weld. The iron may be perfectly joined, yet the structure is weak and uncertain. Wrought iron has a fibrous structure similar to wood. The smith must do his best to continue this structure through the weld. With a lap weld he can start with a heavy upset which can be hammered down. Hammering serves the double purpose of consolidating the metal and of laying the cleavage planes perpendicular to the blows. Much hammering is impossible with jump and butt welds. The lapwelding of wrought-iron pipe and the scarf-welding of chain links must depend on pressure for their perfect finishing. Welds of steel cannot often be much benefited by working. Steel is an alloy, without structure. To be strong it must be solid and homogeneous. Campbell's advice is to keep the critical temperature high and keep down the silicon and phosphorus when choosing your steel.

3. *Too high a heat* is responsible for some bad welds. Very great heat will unsettle the structure of the iron in the stock a considerable distance from the joint. Because the bar breaks near, but not on, the joint, is no proof of the soundness of the weld. The structure of the iron is impaired wherever the heat is beyond the critical point of crystallization of any important impurity. By this is meant that if there be an appreciable amount of carbon, for example, it will tend to mineralize the iron when the latter is cooled down past the crystallization point of the first carbon-iron mineral. A number of other impurities, silicon, aluminum, arsenic, etc., are presumed to act in like manner. So the smith must work his weld and also all of the surrounding metal that has been raised above this critical temperature. Just what is the critical temperature is unknown to him, because it varies with every iron, according to the amount and proportion of its impurities.

Oftentimes welds are made which cannot be worked to advantage. Such welds are apt to be weak. The only present remedy is to select for such purpose iron as free as possible from objectionable impurities. Machine welds, such as small chain

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links and small-bore pipe, where the entire piece must be heated, are especially subject to this disadvantage.

4. *Large welds are unsafe.*

Just what is the maximum cross-section of practicable welding cannot be safely laid down. Welding is not advisable where it is difficult to get a good welding heat, to flux properly, to joint the pieces well and accurately, or to work the weld when made. To weld a ship's sternpost or skeg or rudder-post was a matter of weeks of expensive and often hopeless labor before the advent of thermit (see page 147). To weld a large driving-rod, an embossing die, crushing roll, or propellor shaft was impossible. The largest iron pipe used, however, could be welded; also chain links a foot or more long, and 2- or 3-inch stock could be safely welded.

Campbell says,[1] "Welds of large rods of forging steel are entirely unreliable. Electric methods do not offer a solution of the problem, for during the process the metal is heated far beyond the critical temperature." Thermit, since discovered, does offer a partial solution, because a thermit weld can be reinforced with as much metal as needed, and the metal itself can be varied to meet the requirements. Its cost is to be considered. The oxy-acetylene melt-weld should recommend itself for like reasons. More than one torch can be used for large work (see page 75).

Effect of Impurities, etc.—In order to make a good weld of iron, the metal must possess plasticity, which is directly affected by the contained impurities. The welding temperature seems to be the point at which the iron becomes semiplastic, but is still not sufficiently hot to burn or oxidize rapidly. For the reason that this temperature varies considerably for the different alloys of iron, it is impracticable to make any definite rules. A number of impurities or alloy formers affect the welding property to a marked degree even when present in fractional parts of 1 per cent. Substances which cause "red shortness," such as sulphur, or which oxidize to form an impervious skin, such as aluminum, must be avoided in iron.

In the case of cast iron, which is iron high in carbon and silicon, the metal passes suddenly from a crystalline to a liquid condition.

[1] "Metallurgy of Iron and Steel" p. 588.

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It cannot, therefore, be welded over the smith's forge, and can be welded only by one of the recent special processes.

There are an infinite number of kinds of iron, due to the proportions of the combined impurities and the method of treatment during the milling. Each of these so-called alloys will act differently at the welding temperature, while many of them cannot be welded by the smith at any temperature. There are a few general rules which will help the worker in the selection of his material. But there is so much room for failure in welding the best irons that what cannot be blamed on the smith and his material must be laid to the devil.

Carbon in the combined state should be kept below 0.30 per cent, because it is a hardener and makes brittle in the combined state. Carbon has been found to amalgamate with iron to form a number of alloys, which are unworkable in proportion to their carbon content. W. C. Unwin[1] gives 0.90 carbon as the limit for welding iron with silica flux; 1.10 carbon as the limit with any flux. These alloys,[2] pearile, martensite, cementite, etc., mineralize in the iron and form a granitic structure on cooling. It is likely that all of the mineral impurities of iron behave in this manner.

In the uncombined form, as graphite, carbon does not affect the welding property, except that it becomes an enemy to the homogeneous structure of the metal, just as does slag.

Slow cooling, drawing the temper, keeps the combined carbon at a minimum. Silicon in a quantity approximately over 1 per cent and aluminum even more potently, also reduce combined carbon to graphite. However, the objection to silicon is that it makes a brittle alloy, and aluminum oxidizes to the disadvantage of the metal. Slow cooling is valueless for the reason that welding is done at a high heat, when iron is capable of absorbing carbon in greater quantity.

Hence high carbon in the stock cannot be toned down and should be avoided. It should never be above 0.50, and ought to be below 0.25 for the best results.

Silicon causes brittleness, which does not yield to welding heat. It must be kept below 0.20 per cent. Silicon is the

[1] "Testing of Materials of Construction," W. C. Unwin.
[2] Wm. Campbell, *Electrochemical and Metallurgical Industry*, Feb., 1904.

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element which differentiates cast iron from mild irons and steel. An iron with gray-colored fracture contains too much silicon to use in welding.

Welding Property of Silicon Steels[1]

The weld	Si	C	P	S	Mn
Unsatisfactory	0.21–5.08	0.14–0.26	0.08	0.05	0.14–0.29
Perfect	0.01–0.504	0.16–0.18	0.051–0.121	0.028–0.094	0.455–0.622

It will be noted that the second series of steels gave perfect welds with a content of 0.504 silicon, by above analysis; probably accounted for by the high manganese, which will prevent crystallization.

Phosphorus makes the "rotten iron" for thin and sharp castings when present in quantity approximately over 0.10 per cent. Malleable iron for welds should contain less than 0.03 per cent of it, not so much to assist welding, as to insure a strong joint on cooling.

Sulphur is one of the deadly enemies of the smith. Its effect on iron is especially disastrous at welding temperature, even when not otherwise apparent. In quantity approximating over 0.10, it causes "red shortness," brittleness. It should be kept as low as possible. Manganese is the remedy for sulphur, used in the production of iron, but the smith cannot correct it with manganese himself. Very low sulphur content is the secret of the success of Swedish iron in the arts.

Manganese may be present up to about 1.50 per cent. in iron or steel to be welded. Up to this limit its effect is generally beneficial. Campbell states that between 2 and 6 per cent it forms a brittle unworkable alloy. Hadfeld's steel, with about 7 per cent. manganese, again becomes malleable.

Manganese is the cheapest tonic of the iron producer. It reduces both sulphur and oxygen in the iron and rises to the top as slag. The remainder, if any, forms a tough workable alloy with the iron.

[1] Campbell, "Metallurgy of Iron and Steel."

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Nickel steel welds readily at all compositions. Nickel is a valuable addition to iron, because small percentages of it greatly increase the tensile strength without impairing the elasticity. It is also valuable because it prevents rust in its iron alloys to a marked degree. Nickel steels of from 2.05 to 4.95 per cent nickel are specifically mentioned as weldable if the carbon is kept down.[1]

Chrome steel[2] can be welded. The first hammering must be very gentle so that the metal will not fly to pieces.

Aluminum.—There is some uncertainty about the effect of small quantities in iron. In amounts above 3 per cent it forms a valuable alloy with steel, which is highly fluid on melting. 0.50 per cent increases the tensile strength and elastic limits from 3000 to 8000 pounds and lessens the ductility.[3] Odelstjerna[4] says that only 0.002 aluminum gives inferior steel castings, the fracture being coarsely crystalline.

A serious count against aluminum, if it be true, is that it oxidizes in its alloys and coats them with a skin. This would seriously affect the welding, because this skin is a very refractory, unmanagable substance. Reliable data are wanting.

Copper is generally believed to be harmful in malleable iron. However Campbell[5] in his welding experiments used bars containing 0.35 per cent. with excellent results. He says: "The critical temperature at which the steel ceases to be malleable and weldable varies with every steel. It is lower with each associated increment of copper; it is higher with each unit of manganese, and it is lower in steel that has been cast too hot."

Arsenic steel, with less than 0.20 per cent arsenic will weld as usual. Between 0.20 and 1.20 per cent a flux of borax and sal ammoniac is needed. 2.75 per cent arsenic prevents welding altogether, and the iron behaves like pig iron.[6] Campbell[7] claims that so small an amount as 0.093 impairs the welding property.

[1] *Iron Age*, July 25, 1905.
[2] R. Brown, *Journal of the Iron and Steel Institute*, 1896, Vol. I, p. 472.
[3] "Metallurgy of Iron and Steel," Wm. Campbell, p. 477.
[4] *Transactions American Institute Mining Engineers*, Vol. XXIV, p. 312.
[5] "Metallurgy of Iron and Steel," p. 467.
[6] *Iron Age*, April 13, 1899.
[7] "Metallurgy of Iron and Steel," p. 478.

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He says that 0.20 per cent. of arsenic increases the strength and reduces toughness.

Nitrogen content is not a subject for the smith to bother about. Nitrogen has been blamed recently for otherwise unaccountable failures of chemically good iron. E. J. Sjöstedt[1] claims that infinitesimal quantities of it cause red and yellow shortness. He claims that a furnace producing trisilicate slag gave iron with 0.003 per cent nitrogen; bisilicate slag, 0.016 per cent nitrogen; monosilicate slag, .024 per cent nitrogen. 0.006 per cent, he says, is the limit for good steel and, presumably, for good welding steel.

However, there is at present no easy way of recognizing its presence, and it cannot be guarded against.

Tests of Smith Welds.—Campbell made a series of tests of smithed welds of all of the different kinds of steel and of wrought iron, the results of which are given in tabulated form in his "Metallurgy of Iron and Steel." Four smiths of ability and experience welded the metal in flats and rounds of size and shape most convenient for handling. And though the men knew their bars would be tested, their welds were often far from satisfactory. "Picking out the worst individual weld of each workman, blacksmith 'A' obtained only 70 per cent. of the value of the original bar, 'B' 54 per cent., 'C' 58 per cent., and 'D' only 44 per cent. The forging steel showed one weld with only 48 per cent., the common soft steel 44 per cent., while even the pure basic steel gave one test as low as 59 per cent."

But the tensile strengths of the bars are fairly uniform when compared with the elongation. "In some cases where the break took place away from the weld, the elongation was nearly up to the standard." The elongation test of a basic open-hearth steel of low carbon gave greater elongation in welded pieces than in the natural bar; "but in the other pieces the stretch was low and the fracture so silvery that it was plain the structure of the bar had been ruined. In most cases where the test bar broke in the weld, the pieces parted at the surfaces of contact, showing that no true union had taken place; one or two fractures were homogeneous, but they showed the coarse crystallization that follows overheating."[2]

[1] *Iron Age*, May 5, 1904. [2] "Metallurgy of Iron and Steel," Wm. Campbell.

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Welding Tests of the Royal Prussian Testing Institute[1]

Kind of metal	Ultimate strength lb. per sq. in.		Per cent. elongation in 200 mm. =7.87″		Per cent. of reduction of area	
	Average of 6 tests natural	Average of 9 tests welded	Average of 6 tests natural	Average of 9 tests welded	Average of 6 tests natural	Average of 9 tests welded
Medium O. H. steel .	72110	41820	20.8	3.2	34.9	4.5
Soft O. H. steel	64570	45800	25.1	5.1	44.7	10.5
Puddled iron	57890	47080	22.2	7.7	39.5	14.0

These results agree substantially with those of Campbell. The lowest result for soft steel was 33 per cent., the average 71.

The lowest result for medium steel was 23 per cent., the average 58.

The lowest result for puddled iron was 62 per cent., the average 81.

These results confirm the general impression that puddled iron is the best iron for welding. Contrary to one authority who says that iron before puddling welds more easily because of the presence of the slag in the iron.

The *welding test*[2] is occasionally specified in this country on account of the common use of welds in structural work. Two iron bars of the metal under test, of about 1 inch section, are scarfed, heated to white heat, and joined without flux. The joint is worked with an 8- or 10-pound hammer, and brought down to unit section. It is cooled without chilling. This bar is then tested for tensile and elastic strength; and a similar weld is half cut open, bent until fractured, and examined for structure.

Results of Tests by Prof. Bauschinger

Kind	Section, sq. in.	Ratio of strength at weld to strength of bar, per cent.
Soft steel and ingot iron.	0.15 to 2.00	89, mean, 57 to 105, range
Wrought iron.....	0.15 to 2.00	95, mean, 83 to 102, range

[1] *Journal of the Iron and Steel Institute*, Vol. I, 1883, p. 425.
[2] *Transaction of the American Institute Mining Engineers*, Vol. II, p. 628.

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Welds made with steam hammer were 10 per cent. stronger for mild steel and 5 per cent. stronger for wrought iron on the average than hand welds.

Results of Tests by W. C. Unwin[1]

Percentage of Carbon	Ratio of strength at weld to strength of bar, per cent.	
	Series A	Series B
0.75	59	68
1.00	76	51
1.00	50	84
1.15	89	113
1.15	75	117
1.25	75	86

Results of Tests by David Kirkaldy & Son[2]

Kind	No. of tests	Size of test bar, inches	Ratio of strength at weld to strength of bar, per cent.	
			Mean	Range
Electric weld.....	17	1.129 diam.	89.1	
Smith weld.....	19	1.116 diam.	89.3	
Steel bolts, welded..	28	$\frac{7}{8}$ to $2\frac{1}{2}$ diam.	75.1	71.5 to 88.8
Iron bolts, welded...	181	$\frac{1}{2}$ to $2\frac{1}{2}$ diam.	73.8	61.7 to 88.2
Iron tie-bars, welded.	18	$1\frac{1}{2}$ to 3.13 diam.	59	37 to 74.2
Iron tie-bars, welded.	10	2.5 x (.24 to 68)	76.7	
Iron plates, welded..	7	10 x .87 to 6 x 1.11	65.5	57.7 to 83.9
Iron chain links.....	1086	$\frac{1}{10}$ to 2 (area turned)	86.4	72.1 to 95.4
Bar plate, welded...	14	$\frac{1}{2}$ to $1\frac{1}{8}$ thickness	68.8	52.6 to 82.1

[1] "Testing of Materials of Construction," 1899.
[2] "Strength and Properties of Materials," W. G. Kirkaldy, 1891.

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Conclusions.—Holley[1] gives three conclusions concerning iron:

"1. None of the ingredients except carbon in the proportions present seems very notably to affect the welding by ordinary methods.

"2. The welding power by ordinary methods is varied as much by the amount of reduction in rolling as by the ordinary differences in composition.

"3. The ordinary practice of welding is capable of radical improvement, the most promising field being in the direction of welding in a non-oxidizing atmosphere."

He gives his maximums for the impurities as follows: P, 0.317; S, 0.015; Si, 0.321; Mn, 0.097; Cu, 0.45; Ni, 0.34; Co, 0.11; slag, 2.262.

Campbell's deductions are:

"1. With the exception of manganese in small proportion, the usual impurities in steel reduce its welding power by lowering the critical temperature at which it becomes coarsely crystalline.

"2. A small content of manganese aids welding by preventing crystallization.

"3. Only the purest and softest steels can be welded with any reasonable assurance of success.

"4. The confidence of a smith in his own powers and his belief in the perfection of the weld is no guarantee that the bar is fit to use."

According to Kent:[2] "No welding should be allowed on any steel that enters into structures."

PLATINUM

Though a rare metal, being at this writing more expensive than gold, platinum is much used for analytical apparatus. Between the years 1827–44 it was used by the Russian government for coinage.[3] But it is now largely made into tubes, wire,

[1] "The Strength of Wrought Iron as Affected by its Composition and its Reduction in Rolling." *Transactions American Institute Mining Engineers*, Vol. VI, p. 101.

[2] "Mechanical Engineer's Pocket Book."

[3] Roscoe and Schorlemmer, "Treatise on Chemistry," Vol. II, p. 1350.

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crucibles, receptacles, etc., to be subjected to high temperature and to come in contact with various acids and alkalies necessary for rock analysis; also for leading-in wires for incandescent lamps and for sparking points for electrical apparatus.

Platinum melts at 1760 deg. Cent., is seventh in the malleability scale and first in ductility (Prechtl). Heated in presence of oxygen, it begins to lose weight at 800 deg. Cent. It absorbs hydrogen when heated and gives it off again on cooling, and its surface becomes rough.[1] Like iron, it is highly weldable; best at white heat, though also at a dull red. It does not oxidize in the air, hence needs no flux, though the surfaces should be polished.

The need for welding platinum sometimes arises, as in the case of analysis tubes made of sheet platinum, the joining of tubes, wires, etc., and the fabrication of apparatus and the insertion of patches in burnt-out crucibles.

Before a flame intense enough to melt the metal had been discovered, the platinum refiner took advantage of the welding property in making his ingot. Sponge platinum, resulting from the last stage of refining, was heated to redness. It was then pressed strongly together to form a cake. The cake was heated to white heat and hammered to a compact ingot.[2]

The oxy-hydrogen blast was applied to the heating process about 1847 by Dr. Hare, of Philadelphia; and later the hammering was dispensed with and the platinum was simply melted into an ingot.

Platinum was originally soldered with gold or with difficulty welded. The oxy-hydrogen flame makes the process much easier, as the metal readily melts under this heat. On account of its tendency to absorb hydrogen and consequent bubbling of the surface, it is necessary to keep a slight excess of oxygen in the flame.

The oxy-acetylene flame would also answer the purpose, though it would be necessary to keep a considerable excess of oxygen in the flame. Carbon from the acetylene would rapidly attack the platinum.

I am indebted to Mr. E. A. Colby, of Baker & Co., platinum

[1] Roscoe and Schorlemmer, "Treatise on Chemistry," Vol. II, p. 1350.
[2] Encyclopædia Britannica, Vol. XIX.

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refiners, for the subjoined special information, which covers points hitherto untouched in the literature of platinum and its allied metals.

"The oxy-acetylene flame can undoubtedly be used for the welding of platinum, but is not by ourselves for the reason that the temperature available is far in excess of that necessary, and lack of experience leaves us in doubt as to the effect of the by-products upon the metal from the acetylene flame. We consider the oxy-hydrogen flame far safer and, as the heat is not so concentrated, it is more useful where large surfaces are to be treated. Care, however, must be exercised to have the component gases (hydrogen and oxygen) present in approximately the necessary amounts for perfect combustion. Platinum takes up hydrogen at high temperatures and becomes more or less brittle, depending upon the amount of hydrogen retained.

"No flux is required in the welding of platinum or of other metals of the same group, osmium excepted.

"For the same section, the strength of the weld is undoubtedly weaker than that of the body of the metal. Just how much weaker we cannot state from observation, but, as a welded joint is not submitted to the same mechanical working as the body of the metal, its strength is not to be considered as equivalent. In practice, however, the welded portion is slightly increased in section over the body of the metal, and under these conditions there is no material difference in the strength.

"Iridium, osmium, and other metals of the platinum group, when present in small quantities, do not apparently increase the difficulty of effecting a joint, but the strength of the joint is considerably less, as alloys of platinum and members of that group become more and more brittle with increase of the foreign substances. No difficulty, however, is experienced in welding iridio-platinum containing as high as 30 per cent. iridium. Additions of even minute quantities of osmium to an alloy of this composition, however, make it extremely difficult to obtain satisfactory results.

"Platinum can be united to various other metals, such as copper, nickel, etc., but it is an open question as to whether the union can be considered as a true welding. Undoubtedly, an

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alloy is formed of the two metals at the surface of contact possessing sufficient mechanical strength for the purposes for which such welds are used. The only illustration of welds of this character are to be seen in the construction of the ordinary incandescent lamp, in which the copper wires attached to the filaments are joined to the platinum wires sealed in the glass by fusing a piece of copper onto the end of the platinum wire. This operation is conducted in automatic machines, and has proven very satisfactory for the purpose."

GOLD

Gold is the most easily weldable of all the metals. Like lead, it can be welded cold and, provided it is free from certain impurities, it can be joined at all temperatures. Gold is generally placed first in tables of malleability and ductility. These properties are destroyed by certain impurities, notably antimony, arsenic, and bismuth. One part of bismuth in 1,920 parts gold is alone sufficient to interfere with the working properties of gold.

Pure gold melts at 1062 deg. Cent. and will not oxidize at any temperature. Hence the surface will be clean and weldable. The welding property is very apparent with gold leaf, which must not be allowed to fold on itself lest the surfaces stick together. Gold fillings in dentistry are made by the cold welding of gold leaf.

Pure gold is soft and is seldom used in the arts. To render it strong and durable for coinage and jewelry, it is alloyed with copper and sometimes with silver. Thus the gold coins of Great Britain contain eleven parts gold and one part copper. Those of France and the United States nine parts gold and one part copper. For jewelry both copper and silver are used, the purity of an alloy being designated by the number of *carats* of gold in a total of 24 carats.

The gold of coinage and jewelry cannot be joined without a flux. The flux may be boracic acid or a solution of zinc chlorid and water. In the making and repairing of gold jewelry a mouth blowpipe is used for small and delicate work, and for larger pieces a gas blowpipe with a foot-pump air-blast or compressed air.

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The flux mentioned is used in case the surfaces oxidize when heated. If the gold is so alloyed as to be hard up to the melting point, the weld will be a melt-weld. Low-carat alloys melt considerably lower than pure gold. Hence the melt-weld would be made at about the temperature that high-carat alloys would be plastic enough to weld.

Gold can also be readily welded by electricity.

For ordinary cheap and quick joining in jewelry, gold is soldered with soft solder, a mixture of two parts tin and one part lead. The flux is a solution of zinc chlorid in water. Such a joint is condemned by the best jeweling practice: the joint is not strong; it is a different color than the gold; the solder is apt to destroy the strength of the gold at the joint.

The following table of hard solders, given by Gee,[1] are yellow alloys of high melting point and make strong solders:

Kind	Fine gold	Fine silver	Copper
Best solder.....	12½	4½	3
Medium solder.	10	6	4
Common solder.	8½	6½	5

These alloys are rolled into ribbons and cut up into "pallions," or may be applied in dust made by filing. A description of the soldering of gold would properly belong to a treatise on the goldsmith's art.

SILVER

Silver is also a metal of history. The ancient Greeks knew of it as the metal *electrum*, an alloy of gold and silver, of a brilliant pink-whiteness. Silver is now used largely as a silver-gold or silver-copper alloy, in which the gold or copper is present in approximately 10 per cent. Only rarely is the pure metal used, as for filigree work or for alkali retainers.

Pure silver melts at 960 deg. Cent., and is commonly placed

[1] "The Goldsmith's Handbook," G. E. Gee, p. 136.

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second in tables of ductility and malleability. It does not oxidize in air when heated. All of these qualities point to the supposition that it is readily weldable. But though pure silver is made into filigree work, it is always soldered. The common alloy for jewelry being a combination with copper would suggest at once that soldering or brazing is necessary. In recent years, however, silver has been successfully joined in the electric welder, both to itself and to other metals. Because of its high heat and electric conductance it requires more current, as is also the case with copper.

The joining of silver to silver is effected in jewelry shops with a mouth or gas-air blowpipe and with fine silver as a solder. Other solders are alloys of silver and copper; silver, copper, and zinc; and silver, copper, zinc, and tin. These alloys are given in order of their melting points, the most refractory first. The flux is borax.

It would be well to bear in mind that tin is even more harmful to the working properties of silver than it is to gold and aluminum. Even fumes of tin will alloy with silver and make it brittle. For this reason tin should not be used in solder.

ALUMINUM

Aluminum is one of the youngest of the metals. It was discovered by Wœhler in 1827. At first its considerable expense prevented its being generally used. About 1889, however, the discovery of new processes for its reduction from bauxite, etc., cheapened aluminum, so that it has become a commercial metal. Since then the expiration of the patents covering many of the reduction processes has brought the price still lower.

Fairly pure aluminum is plastic at ordinary temperature, being sixth in ductility and second in malleability.[1] It melts at 655 deg. Cent.; its plasticity increases with heat up to about 600 deg. Cent., when it becomes hot short, and will crumble under the hammer. It is easiest to work between 350 and 400 deg. Cent. Its tensile strength runs from about 14,000 pounds

[1] Aluminum Company of America.

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per square inch for cast bars up to 50,000 pounds per square inch for rolled metal and wire.

It was at first thought that its lightness (sp. gr. 2.6) was its most valuable property. But the experimenters soon found that it formed valuable alloys. The aluminum bronzes, aluminum-iron (about 7 per cent.), and some of the three- and four-metal aluminum alloys were found to be good metals for castings for bearings, and in many instances will eventually displace brass, bronze, and even steel.

Aluminum has two natural disadvantages. It is electropositive and it is difficult to weld or solder. As late as 1903, one of the prominent periodicals[1] said editorially: "Undoubtedly the man who discovers a good aluminum solder will make his fortune, for it is the want of this accessory that seriously hinders the development of aluminum manufactures."

Pure aluminum does not oxidize at ordinary temperature, but when heated becomes coated with a thin film. This film is presumably oxid, though it is so thin that not enough of it can be gathered for analysis. It adheres closely, is rapidly replaced when scraped off, and does not easily flux away. This film covers impure aluminum at ordinary temperature, and it is claimed that aluminum alloys of small percentage are troubled with the surface film. In pouring for aluminum-iron castings there must be only one flow: the molten metal is encased in a skin which retards it, and would hinder the union of two streams in the mold.

Being electropositive to all other metals used in the arts, aluminum soldered joints are troublesome. Electrolytic action sets in, especially when the joint is in contact with water, and the metal at the joint disintegrates. For this reason soldered joints are unsatisfactory.

Many solders for this metal have been recently patented. M. U. Schoop mentions his collection of 50 as being incomplete. Most of these inventions specify a flux that will remove the troublesome film. The solder is generally an alloy of aluminum with zinc, tin, lead, nickel, copper, or silver, or any two or more of these metals in varying proportion. The softer of these solders

[1] *Iron Age*, Dec. 31, 1903.

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are fluxed on with zinc chlorid, mercuric chlorid, tallow, etc.; the harder solders are fluxed with fluorspar, borax, lithium chlorid, etc.[1]

Dr. Richards has invented a self-fluxing solder of a tin and phosphorus alloy. The phosphorus either reduces or dissolves the film that protects the aluminum surface, and the tin alloys with the clean surface. This solder is extensively used. The present composition of this solder is 29 parts tin, 11 zinc, 1 aluminum, and 1 phosphor-tin.[2]

M. U. Schoop, who has also done considerable research work in soldering, has patented a flux. It is a mixture of fluorides of calcium, potassium, or boron and the chlorids of alkali metals, and is covered by British Patent No. 24283, Nov. 26, 1908.[3] This flux may be used before soldering or the cleaned metal may be welded without soldering.

The softer solders are often too weak for good work. All of the solders seem liable to electrolysis. The flux, in a general way, may vary in constitution, should not contain water, and should have a moderately high melting point. It should attack the film, but not the metals. Apparently none of the solders can be guaranteed to last indefinitely on account of electrolysis.

Prof. O. P. Watts,[4] of University of Wisconsin, says: "There has been considerable trouble with solders containing tin and possibly with some others. In some cases destruction may have been due to electrolytic action, but in others it appears to be due to a slow diffusion of the tin in the solid state, resulting in the formation of a layer of a very brittle alloy of aluminum and tin, so that the joint breaks. This is a slow action and may require a year or more for its completion."

Aluminum, as can be guessed by its properties, is a weldable metal, but the tenacious film prevents the natural flow. Accordingly, a flux such as suggested by Schoop is used to clean the surfaces. The pieces of metal to be welded cannot be heated above about 600 deg. Cent., because they will be hot-short.

[1] "Die Gewinnung des Aluminiums," A. Minet.
[2] *The Metal Industry*, 1906, p. 22.
[3] *Electrochemical and Metallurgical Industry*, Jan., 1909.
[4] Special Information.

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In 1906, W. C. Heraeus,[1] of Hanau a. M., exploited a method of welding aluminum that resembles the smith's treatment of malleable iron. It appears, however, that Heraeus' discovery was antedated by the work of Mrs. Emme of this country, who welded aluminum without melting it as early as 1897. Mrs. Emme sued Heraeus for infringement of patent in 1902, won her case, and was afterward bought out by him.[2] The method as described by M. Minet[3] is as follows: The two pieces of aluminum to be welded are polished carefully around the ends, and the surfaces to come in contact are polished. They are then heated with an oxy-hydrogen blow-pipe or Bunsen flame to the proper temperature, 400 deg. C. When this correct temperature is reached, the two pieces are pressed against each other and are hammered and worked as in ordinary welding, the temperature meanwhile being kept the same. The metal flows together at the weld. The success of the operation depends on heating in a complete reducing flame to keep the surfaces bright and on maintaining the proper temperature. It would take a skilled workman. Upon cooling it will be found that the joint will withstand concussion tests and sharp changes of temperature. Dick patented a somewhat similar process in 1900.

The limitation of this practice in welding is obvious. It is not easy to keep the metal ends in a reducing atmosphere, yet they will oxidize rapidly at welding heat in presence of oxygen. And, besides, aluminum is a rapid conductor of heat and, like copper, the heat will travel from the joint unless the flame is very hot.

Cowper-Coles has also done good work in welding aluminum. He has devised a machine in which the bars of aluminum, cleaned and faced off square, are placed and clamped. The bars are heated with a benzene lamp, and when at the plastic point are squeezed together until the metal at the joint forms a considerable blob and the oxid has been forced out of the junction. The weld is then quickly quenched with a jet of water and at the same time a screen shuts off the flame. This contrivance of the inventor's makes a weld that does not have to be worked.

[1] *Iron Age*, Nov. 22, 1900.
[2] Special information.
[3] "Die Gewinnung des Aluminiums," A. Minet.

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Schoop's method is not dissimilar to these three just described; only he cleans the oxid with a dissolving flux before welding. Thus his process does away with the difficulty of cleaning the metal and keeping it clean; the rapid conduction of heat is still a difficulty.

This latter property of aluminum, its high heat conductivity, is of least consequence in the oxy-acetylene welding process, where the estimated temperature of the flame is 3600 deg. Cent. This welding process is especially adapted to aluminum, takes less time, and is sure. The metal pieces need no preliminary cleaning, though if the body of the pieces is large, as with motor cases, it is best to heat the whole casting over a gas flame. This because of the expansion and the rapid conducion of heat from the fresh weld. The operator plays his flame directly on the fracture, using a small melt bar of aluminum to fill up the break and to reinforce the weld. Aluminum melts and behaves like solder under the flame. The operator gets a good melt at the break and works the soft metal in and out with the end of his melt bar. This prevents the solidification of any of the oxid film in the body of the piece.

This weld gives a cast aluminum reinforcement that is stronger than the body of the piece because it can be reinforced. There is no reason why this system of welding aluminum cannot be applied in all instances where aluminum is to be welded. There are *two precautions* necessary. Aluminum melts at 655 deg. Cent.; the temperature of the flame is at least 2000 deg. So the operator must take care that he does not get his metal too hot, or it will run away from the weld. (In the case of mending motor cases, the fracture is placed in a horizontal position and backed with asbestos paper.) Also, the operator should not use the customary high-oxygen flame. If he does his aluminum will scum.

As for strength of the welded joint, Cowper-Coles,[1] who tested twelve consecutive welds of bars, claimed that the metal had not deteriorated. All of the bars broke outside of the weld, and also outside of the range of high heating. There is no doubt, however, that working the metal at the weld is advantageous, just as it is with iron, etc.

[1] *Electrochemist and Metallurgist*, Nov., 1903.

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Conclusion.—From the foregoing, it is plain that aluminum articles must be either welded or riveted—not soldered. It is likely that the manufacturers will soon begin to use this welding property of aluminum more extensively. Riveted ware is unsatisfactory, because the metal is too soft unless alloyed. From the fabrication of kitchen ware to the building up of light, strong metal frames, such as for automobiles, welds would be ideal joints.

COPPER

Copper is one of the oldest, if not the very oldest, metals of history. It was used almost entirely as an alloy with tin or zinc, until recent times. The aborigines of North America, however, found the pure metal already smelted for them on the shores of Lake Superior; and the tools they used we find to-day, made of nearly pure metal, mistakenly said to be "tempered by a lost process."

Pure copper melts at 1080 deg. Cent., is fourth in ductility, and sixth in malleability.[1] If free from certain impurities, such as sulphur and carbon, it becomes plastic above red heat. Under an oxidizing flame it will burn or scale, and part of the scale will be absorbed by the metal surface.

It is a curious fact that, though copper is a weldable metal, as appears from its properties, it is hardly ever welded. The common method of joining copper, brass, and bronze has always been to solder, braze, or rivet the pieces. The welding property is occasionally mentioned,[2] but most metal workers are ignorant of the possibility. While the effect of impurities on the welding property appears not to have been gone into, we may presume that the same substances that cause red shortness and assist in oxidation are also detrimental to welding; and that electrolytic and Lake copper, being nearly pure, are also most weldable. "Over-poled" copper, containing carbon, and copper smelted from sulphid ores are red-short, and generally unworkable.

The fact that the welding of copper is almost an unknown art is strikingly shown by the fact that, in reply to the query of a

[1] Prechtl.
[2] *American Machinist*, Oct. 23, 1902; Schnabel's Metallurgy, p. 1.

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correspondent, the editor of a leading technical publication recently replied as follows: That copper was not weldable; that it flew to pieces if hammered when hot; and that it burned rapidly at welding heat, and would not braze perfectly.

The flux for copper welding usually contains borax or boracic acid and a phosphate salt. One flux recommended is two parts sodium phosphate and one of boracic acid;[1] another is one part yellow potassium prussiate and twenty parts of borax.[2] A pinch of rosin is sometimes added to the flux. When using a phosphate in the flux care must be taken not to bring the copper in contact with free carbon, because copper phosphate will form and will prevent sound welding.[3]

To weld, the metal is heated to redness, when it becomes plastic. The calcined flux is sprinkled on the surface and the pieces are then joined at a yellow heat and hammered together as in iron welding. When using a phosphate flux, do not touch the copper with coke or charcoal. A gas or oil flame is preferable, or the pieces can be heated in an electric welder or with a high-temperature torch. An ordinary hammer and anvil can be used, but on account of the rapid conduction of heat away from the joint, a piece of brick or stone can be substituted for the anvil and a wooden mallet for the iron hammer. Copper at a red or yellow heat is very plastic, if not red-short. So it is well to upset the metal considerably at the joint to allow for working with the hammer.

Copper is welded by the electric process, and a melt-weld can be made with the hydrogen or acetylene burner. But in either case it has been shown that the fibrous structure is destroyed and a crystalline joint occurs. As with wrought iron, the copper weld must be hammered or drawn to restore the fiber. Copper welding is generally considered unsatisfactory, soldering and brazing being preferred, as either can be done below the critical temperature of crystallization.

The smith welding of pure copper is considered more difficult than the smith welding of wrought iron. And because pure copper is inferior in strength to pure iron, it is unlikely that the welding

[1] *American Machinist*, Sept. 25, 1902.
[2] *Ibid.*
[3] *Ibid.*

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property will ever be generally taken advantage of. But the knowledge that copper can be smith welded and that the welds can be made of 100 per cent. strength, may be occasionally found to be useful in the arts.

NICKEL

Nickel is a metal of secondary importance. Its principal use is in nickel alloys, notably nickel-steel, in plating, in coinage, and in the chemical reductions which call for apparatus made of a metal of inertness similar to platinum, but of greater cheapness.

The pure metal is harder than iron, melts at 1451 deg. Cent., slightly below iron, and is malleable and ductile. It resembles iron in being plastic at a bright red or white heat, and is readily weldable at that temperature. As the ordinary nickel of commerce is quite brittle, due to its impurities, it is seen that it will not weld. The welding property of pure nickel, however, is of importance in nickel plating and in making seamed nickel tubes.

One of the chief objections to nickel plate is its tendency to scale or peel off. Electroplated nickel-iron cannot be drawn, bent, or hammered with safety, and frequent changes of temperature will also tend to crack the nickel surface.

Theodore Fleitmann, of Iserlohn, Germany, took out a patent a number of years ago for making nickel-plated iron by mechanical means. Sheets of nickel and iron were heated to welding heat in an atmosphere of hydrogen, after having been polished and fluxed. They were then welded between rolls, without coming in contact with the air. By this method the natural tendency of both metals to oxidize quickly was prevented. At the welding heat the metals alloyed at the contact surfaces, and a plate was produced that could be rolled without detriment to the nickel surface.

In 1903, Thomas A. Edison took out a patent for a somewhat similar idea. The difference was that his nickel was electrolytically deposited, the plate was raised to redness in hydrogen gas by electric current, and then rolled. At first Edison plated iron sheets in a nickel solution, piled them together

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in a clay or cast-iron retort, and raised them to bright redness in a hydrogen atmosphere. At this temperature the metals alloyed and knitted at contact. They were cooled below oxidizing temperature in the same atmosphere before a new change of plates was admitted. Later, Edison improved his process by making it continuous. The iron, in a roll, was passed first through a chamber of hot hydrogen, which reduced all oxids and gave it a fresh surface. From this first chamber it passed into a cooling chamber of the same gas, then through the nickel bath, and the wash-tank; thence through a third hydrogen chamber, where it was raised to welding heat; and lastly to a cooling chamber of hydrogen. The speed was gauged to allow each step of the operation sufficient time.[1]

In 1905, the Standard Welding Company, of Cleveland, exhibited tubes of pure nickel welded electrically. The tubes were strong and the seam was invisible. The present demand for such tubes comes from automobile makers, rubber manufacturers for their end tubes, and industrial chemists for non-oxidizable tubes, retorts, and crucibles.

WELDED PRODUCTS

A great variety of tools, appliances, and parts are welded in some stage of their manufacture. Where pieces of metal are to be joined, welding is the first resort, soldering a poor alternative. As welding is itself a simple process, the chief difference lies in the machinery necessary for different work. In a work of limited scope it will not be necessary to go into the details of the stock welds, but a number of the most important will be mentioned.

The processes of manufacture are in many cases adaptations of the recently discovered processes of welding. The electric process is far ahead for repeat or "stock" welding. The hot flames are best for job work, but are beginning to compete with electricity for "stock" work. Thermit is used mostly for job welding or repairing, but can also be applied to continuous rail or pipe joining.

[1] *The Metal Industry*, Aug., 1904.

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Wrought-iron Pipe.—Pipe welding is about 100 years old, and at this writing the manufacture of welded wrought-iron pipe consumes a large percentage of all the wrought iron made. The first pipe was heated over a coke fire and lap-welded in sections. After the Napoleonic wars gun barrels were a drug on the market and came to be used for water piping. This supply seemed to stimulate the demand, and soon after important inventions began to assist and simplify the original primitive methods. James Russell, who substituted the butt for the lap-welded pipe in 1825, may be called the father of the pipe industry.

Wrought-iron pipes are made in a number of ways. The original lap-weld is still used for its strength. Most pipe is butt-welded from long scarfs of iron, heated in a gas or coke oven, bent round, reheated, and then welded by being drawn over a mandrel and through a die of slightly lower caliber than the pipe. In this way the edges are squeezed together on the outside, while the mandrel pressing on the inside completes the weld. A recent invention is pipe made from a spirally wound and welded strip of iron. Weldless drawn-steel tubing is also finding a market, but so far welded pipe has proved to be cheaper. The process is now a continuous one; and electric welded pipe is now on the market.

Welded pipe is made in sizes of from 1/8 inch to about 30 inches internal diameter. Larger than this, it is generally riveted. The iron must be of very good quality, quite pure, and low in sulphur and carbon. Fifty thousand pounds per square inch tensile strength is as high as it is safe to try to use, as stronger irons than this give weaker welds. High-carbon irons and steels should never be used for pipe, though their initial strength is great. Such metal welds poorly and may easily pull apart at the weld under great pressure.

Chain Making.—Chains made of iron links were known to the first smiths or workers in iron. And though chain is now replaced in many instances by lighter and stronger cables, it is one of the staple iron and steel products. One writer[1] estimates that in 1905 there were in the United States thirty chain mills, having a total yearly output of 50,000 tons of chain.

[1] "The Manufacture of Chain," L. B. Powell, *Iron Age*, Jan. 5, 1905.

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The early chain makers often welded their links at the end, and even made circular links. But modern practice is to make the link an oval and to weld the stock on one side of the link. The stock used varies in diameter from approximately 1/8 inch to over 3 inches, and the links are from 1/2 inch to a foot or more long. Safe practice limits the diameter of the stock from approximately 3/8 inch to 2 inches, as sizes smaller are apt to burn when heated and sizes larger are apt to weld poorly and are unworkable.

Chain is still largely made by hand, and requires skill and care for every link. Speed and a uniform product have been developed by special machines in late years. The links are now cut from a spring-spiral of the iron, are heated in a gas oven, are welded and swaged by a hydraulic press with die of suitable shape. Small chain can now be made on an automatic electric welder.

As with welded pipe, the chain iron should not be of high tensile strength, about 50,000 pounds per square inch, and should be quite pure. The ultimate strength of a chain depends on its design and the perfection of the weld. And as life and property are constantly at the mercy of just one poor weld, the different nations and insurance companies prescribe tests that are approximately double what the chain will be allowed to undergo in practice. In this country the U. S. Testing Board and in Great Britain the British Admiralty Board and Lloyd's restrict the load to 50 per cent. of the ultimate strength of the weakest link.

Miscellaneous.—Other stock welds of importance are carriage tires, frames, hub and axle, and also spoke-and-hub. The carriage industry is founded on the weldability of iron.

Cap screws have larger heads of tough steel welded on by electricity. There are children's hoops, printers' chases, three-ply skate blades, garden rakes, boiler tubing, axe-blades, shotgun barrels, iron rings, wire fences.

The best grade of American anvils are made of a hard quality of steel plate welded on to the top of the block, while the anvil horn is also welded on. The best plows have welded steel points to resist the wear.

Besides these older products, many of the industries which have recently sprung up are using welding apparatus for making

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minor parts of apparatus and machinery—the joining of a durable well-wearing metal on a softer body, one metal to another, or one special casting to another, so as to avoid the use of intricate patterns. Ship-builders weld constantly, though it is bad practice to weld a vital part. Smith welding is used much less than formerly on manufactured articles. The patent welding processes are cheaper, quicker, and safer and are superseding the old hand method.

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PART II—ELECTRIC WELDING

GENERAL

Electric welding processes have been used commercially since about 1880, when Elihu Thomson brought out his low-pressure resistance machine, invented about 1877. In recent years several processes, notably that of Thomson, have become widely known for their successful application to rail welding and to repeat welding of stock pieces in manufactories, such as wheelbarrow spokes, wagon frames, printing chases, etc. Though the several processes in which electric current is used in welding are unlike in apparatus and application, the basic idea of each process is to produce the welding heat by means of resistance to an electric current. The different processes are:

1. La Grange-Hoho process: resistance being set up in an electrolyte.

2. Zerener electric blowpipe: an ordinary electric arc deflected by a magnet.

3. Bernardos arc-welder: the metal to be welded as the positive pole and a carbon negative.

4. Thomson process: in which internal resistance in the metal to be welded generates the heat. This is also called the incandescent process.

The electric welding processes, especially the latter, have followed the adoption of the oxyhydrogen, gas, and oil flames, and slightly antedate the oxy-acetylene and thermit welding methods. The arc-welding systems have followed the commercial introduction of the arc-light in 1881. The internal resistance method was earlier suggested by the experiments of Joule and Moissan. In 1856 Joule welded a bundle of iron wires by burying them in charcoal and heating them with current. While in Moissan's furnace the resistance of a closed metallic circuit (as well as the

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arc-furnace) generated the heat for melting refractory metals and for making alloys.

The Thomson process, the oldest and most important, will here be last described.

THE LA GRANGE-HOHO PROCESS

This process is well called the "water-pail forge." It comes from Belgium and has scarcely been tried out. The metals to be heated are fastened to the negative pole of the circuit and immersed in a bath of an electrolyte, such as potassium carbonate solution. The current when turned on flows from the positive pole through the solution, and returns by way of the metal piece as a negative terminal. The solution begins to decompose, depositing hydrogen on the metal piece in a thin film. The metal piece becomes red- or white-hot, and is protected from the solution by the hydrogen film. As soon as the proper heat is reached, as told by the color of the metal, the pieces are taken out of the solution, and welded or hammered together on an anvil with a hammer.

The advantage of this process is that the metals are perfectly cleansed from grease, dirt, and oxid by the bath, and are protected by the hydrogen film.

The disadvantage is that the heat is not easily controlled. While the working of the hot metal must be done by hand in the air where the metal will soon oxidize.

This process is not likely to have a wide industrial application.

THE ZERENER ELECTRIC BLOWPIPE

Werderman applied the high heat of the electric arc to melting and welding metals. His apparatus was an ordinary flaming arc, the carbons being inclined toward each other. The flame of the arc was directed away in a point from the carbons by means of a blast of air. In a more recent development by Zerener the repulsion of an electromagnet in series with the arc is used to direct the arc against the work. The following points have been charged against this process:

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1. That it is much cheaper than either the oxy-hydrogen or oxy-acetylene flames; because the initial cost of the apparatus is lower and the cost of the energy used is less than the cost of the hot-flame gases for the same amount of work done.

2. That the flame is not easy to control.

3. That the flame is saturated with hot carbon and carbon gas from the pencils. The carbon is taken up by the molten metal, which becomes burnt or brittle.

4. That the intense light of the arc and the high voltage necessary make the welding rather dangerous to the operator.

5. That only a limited-sized flame can be obtained.

The Zerener arc has apparently never been tried out in this country. Abroad it is sometimes used for welding rough work, such as broken castings and pieces that do not need to retain any elasticity. In spite of its several limitations, the cheapness of operation should recommend it to trial.

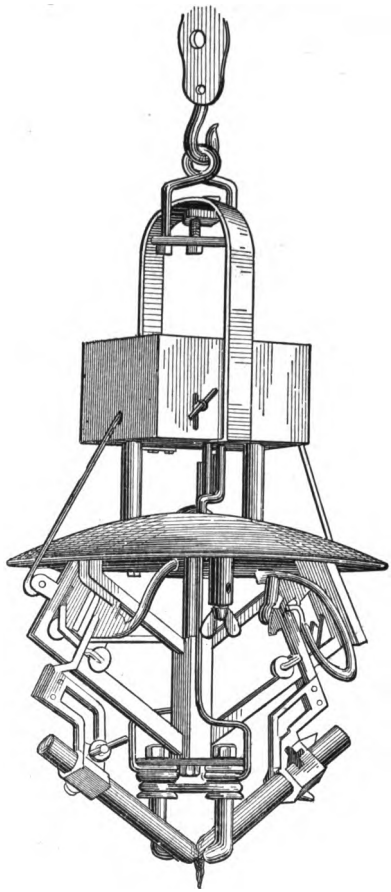

FIG. 10.—Zerener blowpipe apparatus.

THE BERNARDOS ARC-WELDING PROCESS

This arc-welding process is an evolution of the electric furnace. In the electric furnace of Moissan and others the electrodes were both carbon, and the metal to be melted was placed between the carbons in the path of the arc. De Meritens substituted the metal itself for one of the carbons; and later Bernardos, a

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Russian, perfected the process. Coffin has taken out similar patents in America. The Bernardos process has been known in Europe for more than twenty years, and has recently been introduced into this country. Welding heat is obtained by the electric arc. The metal to be welded or melted is the positive

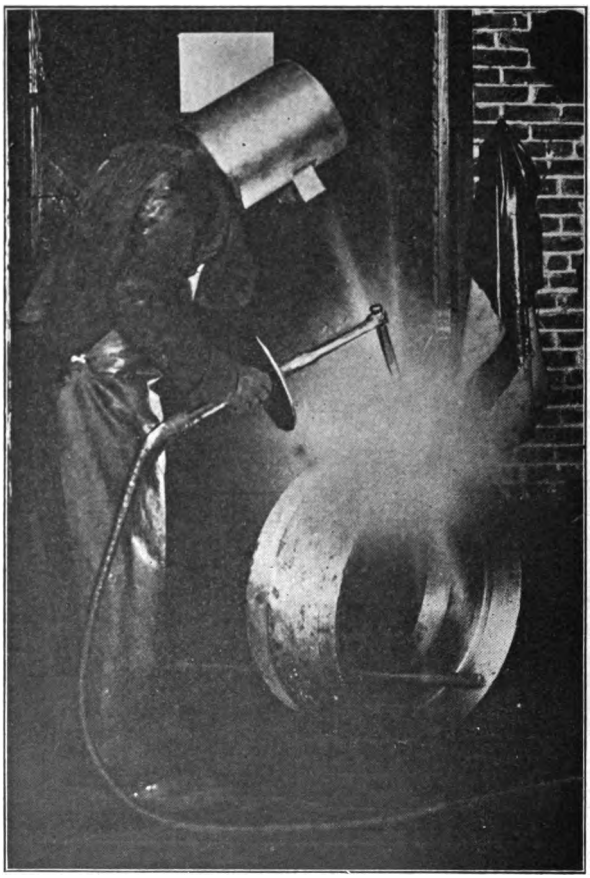

FIG. 11.—Operator welding with Bernardos arc process.

pole. The negative pole is a carbon pencil. The current used is direct, of 100 to 300 volts, and 600 to 1000 amperes. The metal to be welded lies on a metal table to which the positive pole is clamped. The carbon negative is placed in contact with the metal and the current is thrown on. The carbon pole is then

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withdrawn 2 to 4 inches, and an arc is sprung, which follows the carbon wherever the carbon is manipulated by the operator. The greater part of the heat of the arc, about 3500 deg. Cent., is generated in the metal or is reflected back on the metal from the arc. The apparatus used is as follows:

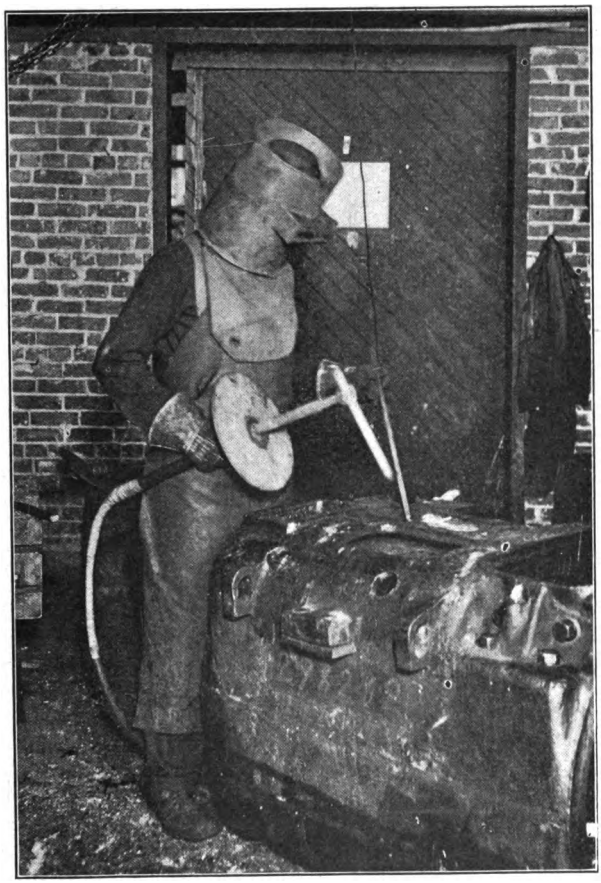

FIG. 12.—Operator welding with Bernardos arc process. (Courtesy proceedings of the Engineering Society of western Pennsylvania, May, 1909, C. B. Auel.)

1. Generator of direct current of 100–300 volts and 600–1000 amperes.

2. A metal table on which to place the work.

3. Leads, switches, and controlling apparatus for the current. carbon pencil.

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4. Protective apparatus for the workman.

Apparatus and Current.—*The Generator.*—It is claimed by the advocates of this system that good results cannot be obtained unless current of ample volume and pressure be used. Current from power wires is generally inadequate. It is best to have a special dynamo of not less than 75 to 100 kw. For reasons given below, the current should be direct. Where the current supplied is alternating, a direct-coupled motor-generator is used to transform to direct current. The motor-generator

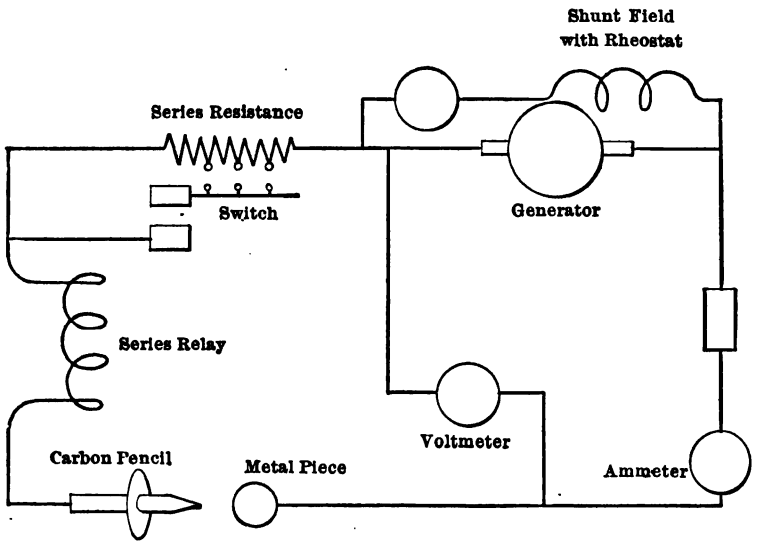

FIG. 13.—Diagram of Bernardos arc welder.

coupling must be flexible to prevent the armature from burning out. This generator will be much the most expensive part of the apparatus—costing more than all the other mechanism.

Direct current is much better and cheaper than alternating. As is well known, the greatest heat is found near the positive pole of the arc. For this reason the metal object to be welded is made the positive pole of a direct current. If it were the negative pole, more heat would be lost and the carbon from the pencil would enter the weld and harden the metal. While if an alternating current were used, some of the carbon would enter the hot metal,

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while the weld would not receive more than half the heat of the arc.

Table, Switches, Controlling Apparatus, Carbon.—The table which holds the work is of cast or wrought iron. The metal to be welded is laid on the table, and it is supposed that the contact between table and metal will be sufficient to carry the current. If the piece of metal is small, the positive lead had better be clamped directly onto the metal instead of the table.

The switchboard contains a single-throw switch and a rheostat connected with grids. Or the rheostat may be made of water-barrels with insulated sides and a terminal plate for a bottom. The other terminal is also a metal plate suspended over the barrel. It is lowered in and out of the water of the barrel.

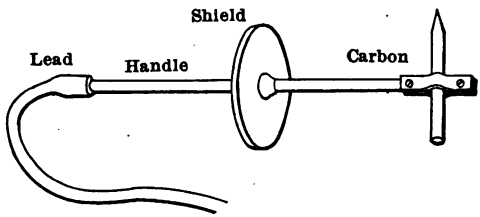

FIG. 14.—Carbon negative pole and shield.

The trouble with barrel rheostats is that the water is liable to boil over under continuous usage, while the barrel hoops will rust rapidly. Circuit breakers should be used to prevent the armature from burning out, in case the operator accidentally short-circuits by touching his carbon pencil to his work.

The carbon pencils are made in sizes of 1/4-inch to 1 1/2-inch diameter by 6 to 12 inches long—of sound carbon. The carbon pencil is fixed into an insulated handle. Midway on the handle is a round shield to protect the operator from the flame of the arc and from sparks (see Fig. 14).

Workman's Protective Apparatus.—Under this head come rubber gloves, a leather or rubber suit or apron, a hood of cloth, stovepipe or wood for the head, and a pair of glasses for the eyes. Bear in mind that the operator is manipulating a current of high voltage and also an arc of great heat and dazzling light. A stove-

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pipe hood for the head is rather unsafe because of the danger of shock. The eye-glasses had better be double, of red and green or red and blue glass, because the light is violent.

Practice.—In practice the metal piece to be welded is clamped onto the metal table. The positive lead is also clamped onto the table or sometimes directly to the metal piece. The carbon electrode is pressed against the metal piece, and the switch is then closed. The operator, clad in his insulated clothing and hood, then draws the carbon pencil away from the piece about 2 to 4 inches and makes the arc. If the arc goes out or is too intense, the current is increased or diminished at the rheostat.

As with the hot-flame processes, the operator now gives his arc a circular movement, taking care to keep the pencil at least 2 and not more than 4 inches from the work. As the metal begins to melt, he works it into the weld with a stick of melt bar, as in the oxy-acetylene process (see page 97). The weld may also be reinforced with scraps of the kind of metal needed. If the metal is brass or zinc, it is best to cover it with a layer of the proper flux.

A slight variation of the Bernardos system is practised in Sweden in the welding of boiler plate. Instead of a carbon negative, a bar of soft steel is used. The bar begins to melt in about a minute and is then pressed on to the weld and the current cut off. The joint of the two plates has already melted and the bar acts as melt bar. The joint is hammered, and the arc is again sprung and more of the bar melted on.

The details of manipulating the torch and metal in this process are not different from the hot-flame processes. Different metals require different treatment in heating, fluxing, and working. Metals that melt to a liquid will have to be built up with a luting of clay or bricks.

It is claimed for the Bernardos process that the metal at the weld is not injured by the heat or the current if the operator follows directions and uses common sense. Iron welds should not be brittle or hard unless the carbon was originally high.

Samuel McCarthy[1] gave the results of comparative tests of the tensile strengths of bars scarf-welded and bars electrically

[1] "Bernardos Arc-welding," read before the Inst. of Mech. Engineers, England.

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welded. The bars were of several different grades of English iron and steel, of cross-section 2 by 1/2 inches approximately. He claims an advantage averaging 18 1/2 per cent. for the arc-welded bars over the smith-welded bars. The arc-welded bars ran from 73.6 to 92 per cent. of the strength of the original stock.

The Bernardos process at present is recommended for general repair work, such as boiler-plate repairing, broken castings, cracked parts, etc. The process is handicapped greatly by the violence of the light and heat of the arc, by the limited size of the flame, and by the danger to the operator from the high voltage. As with the hot-flame process, the heating effect is purely local, and one part of the weld may be getting cold while the other part is being welded. Even heating may be obtained by pre-heating over a gas flame; freedom from shrinkage strains may be had by annealing. The oxy-acetylene flame may be turned on the work from several burners at once. But so far there is but one arc with each welder. It is not likely that two or more arcs will be used together on one job; the only way to increase the size of the work to be welded is to increase the carbon pencil and augment the current. Such increase has sharp limitation.

Cutting Metals with Electric Arc.—The Bernardos arc is also used to cut metals. Its adaptation to metal cutting is of recent date. The arc is held stationary over the plate until the metal is melted in one place. This melted metal is ladled or poured out of the hole by tilting the plate. To obtain a clean-cut hole, it is best to reverse the plate and complete the hole from the other side. If the arc can be manipulated on a horizontal plane or held underneath the plate, the hot metal will flow out of the melt hole of its own accord. A cut in the metal plate is made by advancing the arc along the line of cutting as fast as the metal melts.

This cutting property of the Bernardos arc is somewhat similar to the oxy-acetylene torch (see page 75). The arc is not so efficient as the acetylene torch, however. The latter makes a cleaner and smaller cut and clears the metal away as the flame advances. The cutting arc has been used to cut down the steel piers of the Ferris wheel, for thawing the taps of frozen-up blast

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furnaces, for cutting off parts of castings, and also for mending cracks in castings.

Mr. Auel[1] gives the following table of data for the cutting arc as approximate:

Bernardos Process, Burning Hole in Wrought-iron Plate[2]

Line volts	Amperes	Volts across rheostat	Volts across arc including carbon
120 (open circuit) ..	.....	.....	.....
98	430	23	72
102	400	22	81
104	370	20	86
85	1000 (kick)	24	60
87	1000 (kick)	35	63

THE THOMSON PROCESS

"This process differs radically from all the others in *forcing through the metal to be heated electrically such volumes of current that its own resistance is sufficient to bring every molecule of the section traversed by the current to the desired temperature.*"[3] Current is taken from a lighting or power circuit, is stepped down to the required 3 or more volts and higher volume, and is passed through a secondary circuit in which the greatest resistance is offered by the pieces of the metal to be welded. The cross-section and unit resistivity are so proportioned to the flow of current that the resistance produces red or white heat at the point of welding. The hot metals are then forced together and the weld is made. The apparatus necessary are:

1. A generator of alternating current.
2. A step-down transformer, carried in the body of the welder.
3. Apparatus for regulating the current, and sometimes apparatus for automatically shutting off the current as soon as welding heat is reached.

[1] "Arc Welding," C. B. Auel, *Proceedings of the Engineers' Society of Western Pennsylvania*, May, 1909; presented before the Society, April, 1909.

[2] Size of hole = $1\frac{3}{4}$ inches diameter by $1\frac{1}{2}$ inches deep. Size of carbon = $1\frac{1}{2}$ by 6 inches. Time = 3 minutes 30 seconds (includes 45 seconds for reversing plate).

[3] Hermann Lemp, *The Engineering Magazine*, Aug., 1894.

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4. Clamps for holding the metal to be welded and to transmit the current to it.

The Thomson process presents a number of decided advantages. Among them:

1. It is at present the best all-around welding machine for welding continuous runs of one weld, such as printers' chases.

2. The power used is claimed to give a 75 per cent. heat efficiency; the power is used only as long as needed, and is turned off as readily as the hot-flame welding burners.

3. The heating is rapid, even, entirely local, and is under control.

4. There is no excessive heating as with the electric arc; hence no excessive oxidation or decarbonizing of the metal.

5. The clamps hold the work in accurate alignment and furnish pressure enough to squeeze well the hot metal.

6. The workman is in no danger of injuring his eyes by excessive light, nor is the current at all dangerous. The operator works without dark glasses or protective apron and can hold the metal bars while the welding is going on.

The present limitations of the process seem to be:

1. Though it will weld odd or job work, it is practically limited to continuous welding of one article, known as *repeat welding*.

2. Though such metals as brass and cast iron can be welded on the Thomson machine, the company does not recommend it for such metals as have a marked melting point and which are not plastic below that point. High-carbon steel does not give an altogether satisfactory weld with this process.

3. The machine demands power at irregular intervals. For this reason station engineers may object to having a single machine of large size on their lines.

Apparatus and Current.—*The Generator.*—Welding work can be done with current from city lighting circuit or the firms will sell a generator built for the purpose. A machine built for sizes of iron and steel not more than 1/3 inch square may be connected to the city alternating lighting wires at 54 or 104 volts, requiring no transformer. For work larger than 1/3 inch square section it is best to get the alternating generator made

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for the machine. The following is a table of dynamos especially adapted to welding:

Generators Specially Adapted for Electric Welding, 220 to 3300 Volts (Warren Electric Mfg. Co.)

K. W.	R.P.M.	Approx. Weight	Price list	K. W. exciter	Exciter R. P. M.	Standard Pulley D.	Standard Pulley F.
22.5	900	3100	1250.00	1	1725	21½	4½
30	1200	3200	1300.00	1	1725	16	4½
50	900	4900	1700.00	1	1725	21½	7½
60	900	6500	1850.00	1½	1600	21½	10
60	720	8200	2200.90	1½	1600	27	9½
60	600	9100	2550.00	1½	1600	32	9½
75	720	9400	2550.00	2	1450	27	12½
75	600	10500	2800.00	2	1450	32	12½
90	720	10800	2800.00	2	1450	27	15
100	600	12000	3200.00	2	1450	32	15

In this process alternating current is invariably used, though there is no electrical reason why direct current should not be used. It is claimed for alternating current that its heating action is more uniform. As it flows mostly on the surface of the conductor, its heating effect begins and is most intense on the surface. This heat is evenly conducted to the core of the welded pieces; thus the radiation and conductance are offset. The periodicity of the current may vary between 50 and 250. As low as 20 may be used. Guarini[1] recommends 80 to 250 on welds of 4-inch square section, which, however, is larger than work ordinarily welded by electricity. The lower the periodicity, the less will be the skin effect, and hence the less the tendency for the current to crowd toward the outside of the parts to be welded. The Thomson machine is now designed for alternating current of 40 to 60 cycles.

Figure 15 shows the Thomson apparatus diagramatically.

The Transformer.—Current from a lighting circuit of 54 or 104 volts can be carried directly to the welding clamps without

[1] *Scientific American Supplement*, Nov. 5, 1904.

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being transformed. Such a welder is called a direct welder, and is used for small work only. With current of a 220- or 440-volt circuit a transformer is necessary. Besides which, it is safest and cheapest to use a current of not more than 4 to 10 volts in any event.

The transformer used is of the core type. It consists of a core of soft iron surrounded with the primary and secondary coils, the first of which introduces the primary current at relatively high voltage and low amperage, and the second of which leads off the current for the secondary or welding circuit at

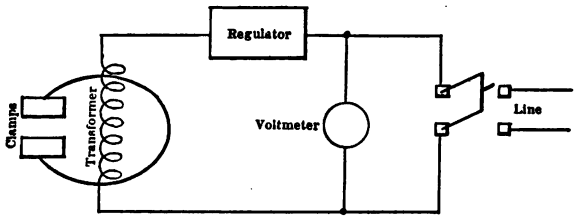

FIG. 15.—Diagram of Thomson electric welder.

relatively low voltage and high amperage. The secondary coil is a solid copper casting encircling the core. In the larger machines, the heating effect of the current transformation is overcome by passing a steady current of oil over the transformer which is encased in a tight box. This oil is either air- or water-cooled.

Figure 16 shows a machine with two transformers, one for heating and one for welding. The machine is described as follows:

"There are two separate transformers in the machine, on one of which is mounted a gun-metal platen, sliding on the right-hand or welding transformer. The left-hand contact, or electrode, is located between the contacts of the heating transformer and is adjustable for any required space between the electrodes of the two transformers by a screw at the left of the welder; the right-hand platen being moved to and from the left-hand contact by the pressure lever at the right. The cam levers, which hold the piece to be welded tightly on the electrodes, are fastened to

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the cast-iron bracket, and are adjustable to varying thicknesses of stock.

"The circuit in the transformers is opened and closed by two pole break-switches, which are furnished with the welder and should preferably be installed at the back of the machine; treadles, which are connected by chains to the break-switches, project under and at the front of the welder, and are operated by foot.

"One piece is laid on the terminals of the heating transformer in the direction of front to back of the welder, and is securely

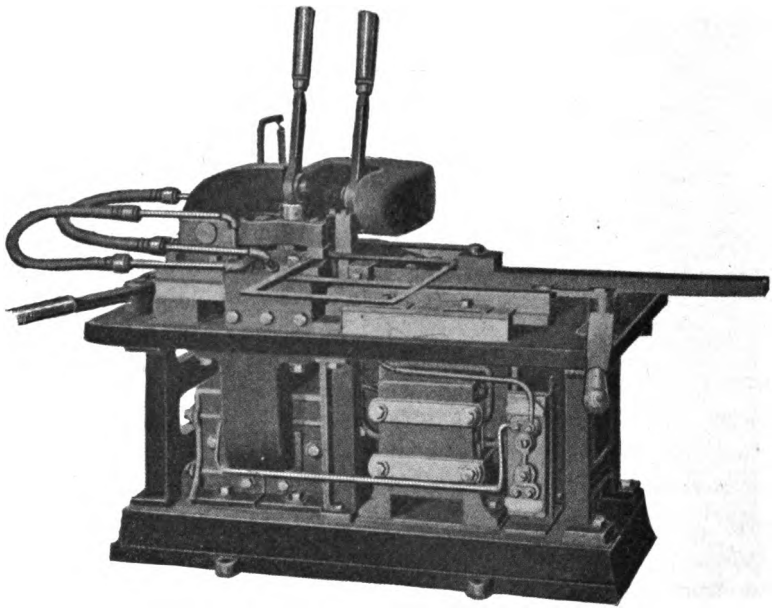

FIG. 16.—Thomson double transformer electric welder, for dash and fender frames. The clamping device can be modified to take other right-angle and of welds.

held by bringing forward the cam lever, the circuit is then closed by placing the left foot on the break-switch lever, and, while the piece is rapidly heating between the electrodes, the other piece is laid on the electrodes of the right-hand or welding transformer and tightly clamped by the other cam lever. The foot is then released from the break-switch treadle of the heating transformer and transferred to that of the welding transformer, when the second piece, immediately coming to a welding heat, is forced

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against the heated section of the first piece by the pressure lever, upsetting against and fusing with it. The foot is then removed from the break-switch treadle, and the cam levers are thrown back, releasing the welded pieces."

The transformer is the heaviest part of the welding machine. So it is placed in the body of the welder frame, underneath the clamping table. It thus gives stability to the machine. Figure 16 shows the transformers in plain sight. In figure 21 the transformer is covered from view in the body.

Typical Thomson Welders

Weight in pounds	Floor space		Maximum watts	Maximum area □″		H. P. to dynamo
	Length	Width		Iron	Copper	
125	13″	12″	1,000	.05	.....	2
150	15″	12″	2,000	.10	.....	4
140	13″	14″	2,000	.....	.0209	4
525	27″	15″	5,000	.30	.110	9
800	28″	18″	7,000	.25	.....	12
900	32″	20″	10,000	.60	.20	17
2,200	54″	30″	20,000	1.23	.40	35
2,400	70″	30″	20,000	1.23	.40	35
7,000	90″	36″	40,000	3.	.79	80

Regulating Apparatus.—Regulating apparatus includes a switch-board on which are assembled a reactive coil, rheostat, potential indicator, and fuse blocks and switches; and apparatus for automatically shutting off the current of the primary when welding heat is reached.

The reactive coil (Fig. 17) is to control the current at the welder when a great variety of sizes is to be welded. It consists of an iron base, a copper hood, a switch, and two laminated iron cores; the smaller core carries the copper hood and partly rotates within the larger core which has four distinct coils wound on it. These coils can be connected either in series, series multiple, or multiple, by means of the switch in the base, which is operated by the handle projecting through side of base. The hood is moved over the winding by a worm gear, which is operated by the wheel at the front.

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When the switch handle is in position No. 1 and the hood farthest away from the winding, the minimum current is obtained.

When the switch handle is in position No. 2 and the hood farthest away from the winding, the mean current is obtained.

When the switch handle is in position No. 3 and the hood over the winding, the maximum current is obtained.

The reactive coil also regulates the potential for metals like iron, which are good conductors when cold and become more resistant when hot.

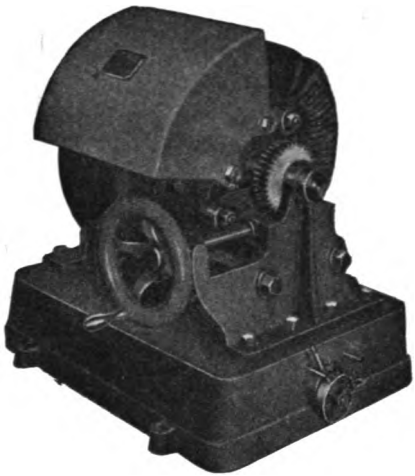

FIG. 17.—Thomson type reactive coil, for controlling current in welding machine.

A fairly efficient makeshift rheostat was formerly made of a barrel of water into which a metal disk was lowered and raised. The disk served as one pole and the bottom of the barrel as the other pole. The sides of the barrel were insulated.

Regarding the high peak loads caused by a large Thomson machine, *The Electrical Times*[1] has this to say:

"Central station engineers have hitherto been somewhat chary in connecting electric welders of large size to their mains on account of the fluctuating nature of the load, although there are numerous instances of small welders being so used. A very interesting installation has recently been completed in London by the Electric Welding Company, Limited, in which a welder of 90 k.w. capacity is worked off a single-phase power supply at 400 volts. In order to prevent undue fluctuations of voltage on the mains, a special substitutional resistance is installed, built in three sections, each controlled by a switch, so that one or more sections can be put in circuit according to the size of the work being welded. A large liquid resistance is also employed to prevent an undue rush of current, when the primary circuit

[1] September 5, 1907.

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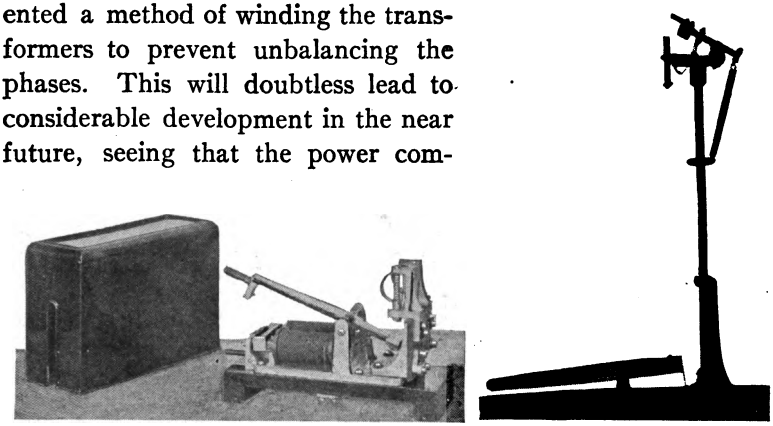
of the welding transformer is closed, the plates being raised and lowered by a small motor through suitable gearing. The controlling switch of the welder is so arranged that when put in the 'on' position it starts the plate-lowering gear, thus gradually cutting out the starting resistance, and *vice versa*. This plant is in continuous operation, and no inconvenience to other power users in the neighborhood has been reported. Another welder of smaller size has also been connected to this circuit. In this case a special economy coil is used as a regulating device.

"To facilitate the working of electric welding machines on polyphase circuits, Professor Elihu Thomson has recently patented a method of winding the transformers to prevent unbalancing the phases. This will doubtless lead to considerable development in the near future, seeing that the power companies' supply mains are available in most manufacturing centres."



A *B*

FIG. 18.—Two types of Thomson automatic break switches.

On account of the type of welds it handles, the Thomson welder is often made automatic. Suppose a welder is being fed links of a chain to be welded. If the welder will put through each weld automatically, a uniform product will be secured and labor, time, and current will be saved. The automatic shut-off (Fig. 18, *a*) is a switch in the primary circuit which is thrown open as soon as the clamps move together on the yielding metal. The current is not used any longer than is necessary to heat the joint.

The break-switch shown in figure 18, *a* is used with the larger welders, heavy currents being employed, and should be installed

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[illegible] position No. 1 and the hood [illegible] the minimum current is obtained. [illegible] position No. 2 and the hood [illegible] the mean current is obtained. [illegible] position No. 3 and the hood [illegible] current is obtained.

[illegible] the potential for metals like [illegible] which are good conductors when cold and become more resistant when [illegible].

A fairly efficient make-shift rheostat was formerly made of a barrel of water [illegible] which a metal disk was [illegible] and raised. The disk served as one pole and the bottom of the barrel as the other pole. The sides of the barrel were insulated.

Regarding the high peak [illegible] caused by a large Thomson machine, The Electrical Times has this to say: [illegible] been somewhat [illegible] size to their mains [illegible] although there [illegible] being so used. A very [illegible] been completed in London [illegible] in which a welder [illegible] a single-phase power supply [illegible] fluctuations of voltage [illegible] resistance is installed, built [illegible] so that one or more [illegible] according to the size of the wor[illegible] resistance is also employed [illegible] when the primary circ[illegible]

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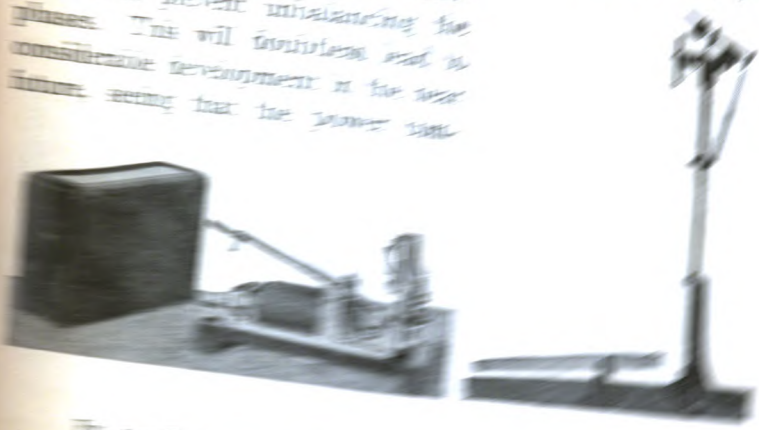
of the welding transformer is closed, the plates being raised and lowered by a small motor through suitable gearing. The controlling switch of the welder is so arranged that when put in the "on" position it starts the plate-lowering gear, [illegible] cutting out the starting resistance, and [illegible] is in continuous operation, and [illegible] users in the neighborhood [illegible] of smaller size has also been [illegible] a special economy coil [illegible]

[illegible] facilitate the working of [illegible] Professor Elihu Thomson has recently [illegible] a method of winding the transformers to prevent unbalancing the phases. This will doubtless lead to considerable development in the near future, seeing that the power [illegible]



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at the back of the welder. The switch is out of reach and is operated with the foot by the lever; this lever should run under the base of the welder, the end projecting at the front of the welder at a convenient place for the operator.

The break-switch shown in figure 18, *b* is used with the smaller welders for wire and thin flat sections, etc., when the weld is made instantaneously and should be installed at a convenient height against the left of the welder. The switch is operated by hand, the lever being pressed down on to the shoulder at the front.

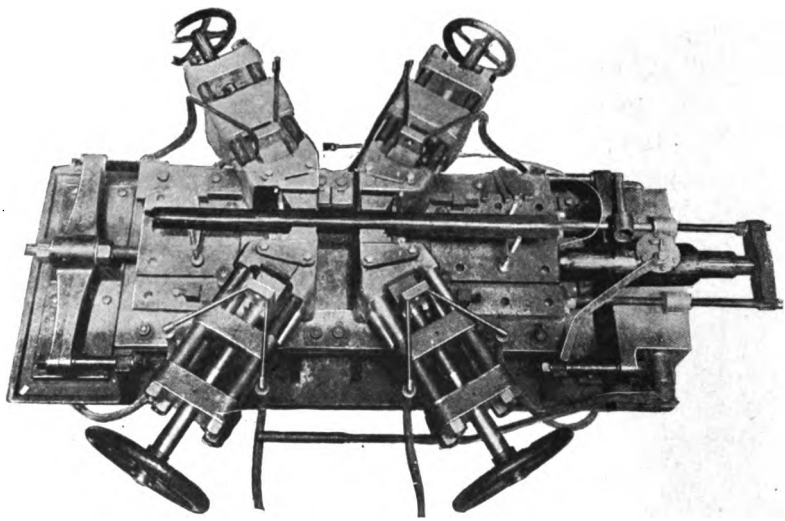

FIG. 19.—Thomson universal welder with horizontal oblique clamping device and hydraulic jack for pipe straight-away and miscellaneous work.

where it locks, being automatically released when the weld is made, by a cut-out device on the welder, a spring throwing up the lever.

When the piece to be welded does not heat evenly, the lever should be lightly and intermittently pressed against the shoulder without locking, until the heat is evenly distributed, when it should be locked, as before stated.

The Clamps.—The clamps vary in design in different types of machines. Figures 16 and 19 show clamps for various work. They are generally of heavy copper, to allow for the passage of the large volume of current. The clamps are not rigid in a welding

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machine, but are pivoted or mounted on a straight sliding groove, and are made to move toward each other by a lever, wheel-and-screw, or by hydraulic pressure. Recently the hydraulic pressure has been made automatic, so that the machine will throw on its own current as soon as the pieces to be welded are clamped, will

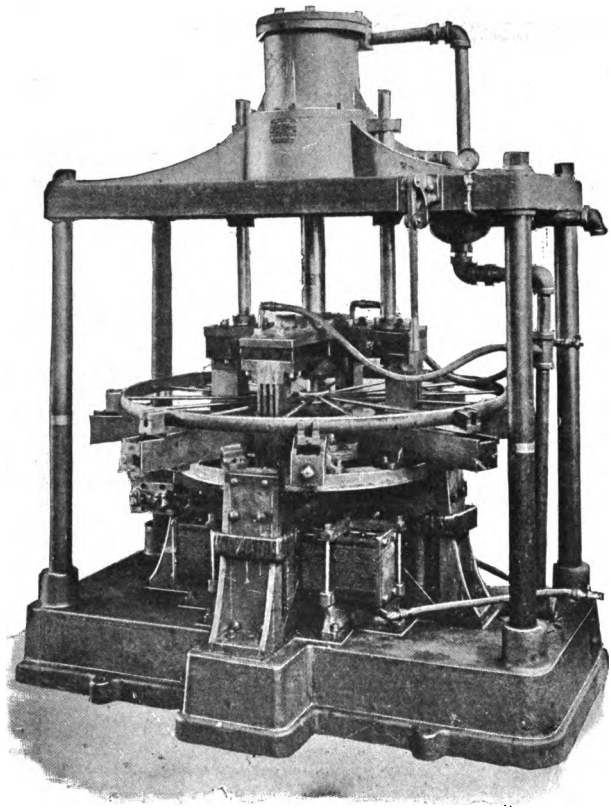

FIG. 20.—Thomson special machine for welding hubs and spokes in agricultural wheels. Approximate weight 7,500 pounds.

squeeze the pieces together at the temperature of plasticity, and will throw off the current at the same time.

Where heavy bars are to be welded, and a good electrical contact is needed at the clamps, the clamps are operated hydraulically.

As will be guessed, the clamps are liable to get very hot,

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Representative Thomson Welders

No.	Type of welder	Kind of work	Round		Flat		Crescent		Channel		If circle min. dia.		Aprox. weight lbs.		Max. watts cap.	No.
			Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.			Net	Gross		
1	1 A A Hand automatic.	Copper wire.....	No. 23	No. 15	.....	.....	....	....	....	....	No. 23 No. 15	1″ 2″	92	120	1,500	1
2	2 A Hand automatic....	Iron and steel wire.	No. 16	No. 8	.....	.....	....	....	....	....	No. 16 No. 8	1½″ 6″	150	200	3,000	2
3	2 A A Hand automatic.	Copper wire.....	No. 16	No. 6	.....	.....	....	....	....	....	No. 16 No. 6	1″ 6″	140	190	3,000	3
4	2 A Automatic.....	Iron and steel wire hoops.	No. 14	No. 11	.....	.....	....	....	....	....	No. 14 No. 11	1½″ 2″	150	200	3,000	4
5	3 A Automatic.....	Iron and steel wire hoops.	No. 10	No. 8	.....	.....	....	....	....	....	No. 10 No. 8	2″ 2½″	300	380	4,500	5
6	5 A Hand automatic ...	Iron and steel wire.	No. 8	⅜″	.....	.....	....	....	....	....	No. 8 ⅜″	2½″ 6″	525	665	7,500	6
7	5 A Standard.....	Iron and steel.....	No. 8	⅜″	⅜″x$\frac{1}{16}$″	1″x⅛″	⅜″	½″	....	½″	No. 8 ⅜″	2″ 6″	525	665	7,500	7
8	5 A A Hand automatic .	Copper wire.....	No. 6	$\frac{5}{16}$″	$\frac{3}{16}$″x$\frac{3}{8}$″	⅜″x$\frac{3}{8}$″	....	....	....	....	No. 6 $\frac{5}{16}$″	3″ 8″	550	700	7,500	8
9	7 A Automatic.....	Iron and steel square or rectangular frames.	No. 8	¼″	.....	.....	....	....	....	....	No. 8 ¼″	2″ 6″	800	900	6,000	9
10	10 A Cortland	Right angles and carriage rails.	¼″	½″	.....	1¼″x⅜″	....	....	....	....	.....	....	900	1,100	15,000	10
11	10 A Standard.....	Iron and steel.....	¼″	½″	½″x⅛″	1¼″x¼″ 2″x$\frac{1}{16}$″	⅜″	1¼″	½″	1″	¼″ ½″	2″ 10″	900	1,100	15,000	11
12	10 A Double transformer.	Right angles and dash and fender frames.	¼″	⅜″	.....	⅝″x¼″	....	....	....	....	.....	....	900	1,100	10,000	12
13	20 A Pipe.....	Extra heavy iron and steel pipe.	¾″	2″	.....	2½″x⅜″	Solid rounds and squares can also be welded from ½ to 1½ sq. in.				.....	....	2,600	3,000	30,000	13
14	20 A Standard, quick operating clamp.	Iron and steel flat stock.	½″	¾″	¾″x$\frac{1}{16}$″	2¾″x¼″ 2¾″x$\frac{1}{16}$″	1″	2″	⅜″	1¼″	½″ ¾″	5″ 8″	2,500	2,900	30,000	14
15	20 A Automobile rims ...	Iron and steel flats.	.....	.....	1″x⅛″	4½″x$\frac{3}{16}$″	Some simple forms in profile can also be welded.				1″x½″ 4½″x$\frac{3}{16}$″	20″ 24″	2,500	2,900	30,000	15

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Representative Thomson Welders—Continued

No.	Type of welder	Kind of work	Round		Flat		Crescent		Channel		If circle min. dia.		Aprox. weight lbs.		Max. watts cap.	No.
			Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.			Net	Gross		
16	20 A Vertical oblique, fast operating clamp.	Iron and steel axles and tires.	$\frac{1}{2}''$	$1\frac{1}{4}''$	$1\frac{1}{4}''x\frac{1}{4}''$	$3''x\frac{5}{16}''$	1″	2″	$\frac{3}{8}''$	2″	$\frac{1}{2}''$ $1\frac{1}{4}''$	5″ 25″	2,700	3,100	30,000	16
17	20 A Vertical screw medium fast operating clamp.	Iron and steel axles, tires, channels and disks.	$\frac{1}{2}''$	$1\frac{1}{4}''$	$1\frac{1}{4}''x\frac{1}{4}''$	$2\frac{3}{4}''x\frac{1}{16}''$ $2''x\frac{5}{16}''$	1″	2″	$\frac{3}{8}''$	2″	$\frac{1}{2}''$ $1\frac{1}{4}''$	5″ 25″	2,800	3,200	30,000	17
18	20 A Pipe	Steel tubing	$\frac{1}{2}''$o.d.	$1\frac{1}{2}'$o.d.	$1\frac{1}{4}''x\frac{1}{4}''$	$2\frac{1}{2}''x\frac{3}{8}''$	Solid rounds and squares can also be welded up to $1\frac{1}{4}$ sq. in.				.....	....	2,700	3,100	30,000	18
19	40 A Horizontal	Iron and steel axles and tires.	$\frac{3}{4}''$	2″	$1\frac{1}{4}''x\frac{3}{8}''$	$4''x\frac{1}{2}''$	2″	3″	$\frac{3}{4}''$	2″	$\frac{3}{4}''$ 2″	5″ 40″	7,200	7,800	60,000	19
20	40 A Pipe	Extra heavy iron and steel pipe.	1″	3″	.....	$3\frac{1}{2}''x\frac{1}{4}''$	Solid rounds and squares can also be welded up to 3 sq. in.				.....	....	7,200	7,800	60,000	20
21	40 A Rod	Iron and steel axles, etc.	$\frac{3}{4}''$	2″	$1\frac{1}{4}''x\frac{3}{8}''$	$4''x\frac{1}{2}''$	....	....	....	....	$\frac{3}{4}''$ 2″	5″ 40″	7,200	7,800	60,000	21
22	40 A Automobile rims	Iron and steel flats.	.....	.....	$2''x\frac{1}{8}''$	$4\frac{3}{4}''x\frac{5}{16}''$	Some simple forms in profile can also be welded.				1″x$\frac{1}{4}''$ $4\frac{3}{4}''x\frac{5}{16}''$	20″ 28″	7,000	7,600	60,000	22

Copper wire B. & S. gauge. Iron and steel wire W. & M. gauge.

Right angles $\frac{3}{8}$ of sizes of rounds and flats can be welded on Nos. 16 and 17 welders, also disks up to $2\frac{1}{2}$ x $\frac{3}{8}$ on No. 16 and 4 x $\frac{1}{4}$ on No. 17 welders, not less than 10 inches in diameter.

Squares and ovals can be welded in all welders equal in sections to rounds and flats, except No. 10 welder in which the limit is $\frac{3}{4}$ x 7/16 oval.

Reactive coils are not required with the following welders numbered 1, 4, 5, 9, 10, 12, 13, 16, 19, 20, 21. When only the maximum sizes of stock are to be welded, no reactive coil is required with any welder; but when the minimum sizes, or all sizes within the capacity of the machine are to be welded, a reactive coil is required: Type 2 EE with welders numbered 2, 3, 6, 7, 8; Type 4 EE with welder numbered 11; Type 10 EE with welders numbered 14, 15, 17, 18; and Type 20 EE with welder numbered 22. When less than 220 volts is used, or when the welder is to be operated to its utmost capacity in output on maximum size of work, the next size reactive coil is recommended.

Weight of Reactive Coils

	Approximate net and gross weight; lbs.	
Type 2 EE, Reactive Coil,	120	175
" 4 " " "	190	265
" 10 " " "	400	500
" 20 " " "	600	700

An *alternating* current is absolutely required; a direct current cannot be used. The welders are built for 50 cycles, but up to and including 5A they are sometimes used on a circuit as high as 125 cycles, but never lower than 50 cycles. Welders larger than 5A can be used to the best advantage on circuits between 40 and 60 cycles.

Any voltage from 100 to 350 can be used for the smaller welders, and from 200 to 350 for the larger; but it must be constant and not drop during the time of heating the stock.

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especially on continuous runs of heavy work. As heat affects the conductivity of the clamps, they are often water-cooled.

Some of the automatic machines are equipped with swages working between the electrodes. These swages are brought together on the weld immediately after the hot metal is upset. They compress the upset or bur and give the weld any desired shape. Besides which, their pressure amounts to working of the metal and makes the weld much stronger.

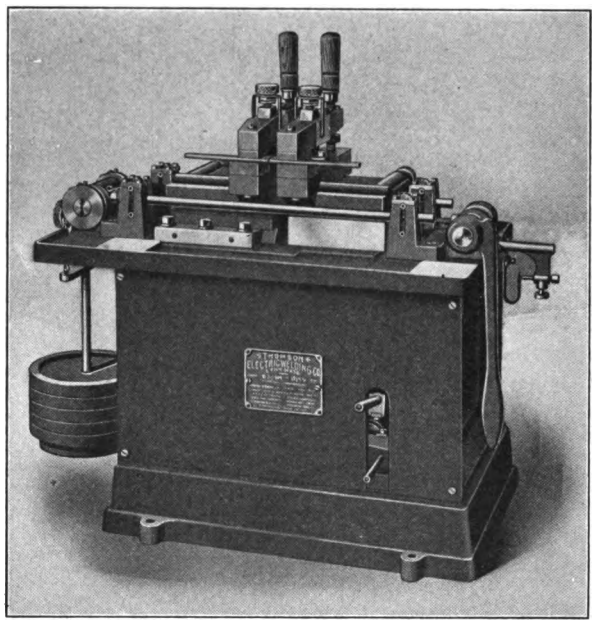

FIG. 21.—Thomson type 5 AA electric welder for copper wire from No. 6 to 1–4 inch. Time in heating from 2 to 6 seconds. 7500 Watt alternating current, not lower than 50 cycles, from 100 to 350 volts.

Practice.—The operation of the Thomson electric welder is very simple, calling for much less skill than the hot-flame processes. For stock welds the current is first calculated for the size of the piece to be welded and the kind of metal in the piece. Tables of current value, cross-section, and time have been worked out for iron, steel, brass, and copper (see page 52). The machine being adjusted for stock welds will handle them rapidly without

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readjustment, much the same as a printing press will run off many impressions of the same form.

The operator places his pieces in the clamps, closes the clamps, and advances the clamps toward each other until the two pieces touch closely. He turns on the current and as soon as the pieces, become plastic or semi-molten at the point of contact he turns off the current and squeezes the clamps toward each other until the pieces become welded and upset at the contact.

Figure 21 shows a semi-automatic machine. The copper contacts, carrying the clamping device, move to and from each other: the left is moved by a screw to get the required opening between clamps; the right is held apart by the lever. The wire is inserted and tightly held in the clamps, the side lever raised, the circuit closed through the hand-automatic break-switch in the base of the welder, and the pieces, instantly heating at the joint, are forced together by the weights; the circuit being automatically opened by the adjustable cut-out device.

In making the joint, the metal is upset, the extent of which depends largely upon the weights and the adjustment of the cut-out device.

When full range of sizes is to be welded or when the smaller sizes only are to be welded, a current controller is furnished with the welder.

Energy Absorbed in Electric Welding—Prof. Thomson's Process

Iron and steel					Brass					Copper				
Area in ″	Watts in primy. of welders	Time in ″	H. P. applied to dynamos	Foot-lbs. unit 1000	Area in □″	Watts in primy. of welders	Time in ″	H. P. applied to dynamos	Foot-lbs. unit 1000	Area in ″	Watts in primy. of welders	Time in ″	H. P. applied to dynamos	Foot-lbs. unit 1000
0.5	8550	33	14.4	260	.25	7500	17	12.6	117	.125	6000	8	10.	44
1.	16700	45	28.0	692	.5	13500	22	22.6	281	.25	14000	11	23.4	142
1.5	23500	55	39.4	1191	.75	19000	29	31.8	508	.375	19000	13	31.8	227
2.	29000	65	48.6	1738	1.	25000	33	42.0	760	.5	25000	16	42.	369
2.5	34000	70	57.0	2194	1.25	31000	38	52.0	1087	.625	31000	18	51.9	513
3.	39000	78	65.4	2804	1.5	36000	42	60.3	1390	.75	36500	21	61.2	706
3.5	44000	85	73.7	3447	1.75	40000	45	67.0	1659	.875	43000	22	72.9	872
4.	50000	90	83.8	4148	2.	44000	48	73.7	1947	1.	49000	23	82.1	1039

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Iron and Copper

	Sp. heat	Cond.	Melting point, deg. Cent.	Arcing volts
Iron.....	0.113	374	1635	25
Copper.....	0.095	898	1080	23

Copper requires two or three times as much power and only 0.6 time as long time as iron. Rectangular pieces require 25 to 50 per cent. more power than circular. A machine that will weld 2-inch iron will take 1 1/4-inch brass and 7/8-inch copper.

As is seen by the tables, the actual time of welding after the current is turned on is often less than one minute per weld; the advantage of quick handling, automatic clamping, and automatic current shut-off are very apparent. With skilled labor and automatic machines, many firms are now turning out from 500 to 3000 welds per machine per ten-hour day.

For job work the welder is slower and a skilled man should be the operator. If he is called on to weld a succession of different sizes, shapes, and different metals he will have to use his gray matter continually in the regulation of the current, clamps, and the amount of uspet and time of cooling before removal from the clamps. Many firms use this welder for job welding, though it is not specially adapted to job work.

A number of precautions are necessary in the different steps of welding. In the first place, the metal should be very clean, both at the clamps and at the points of contact where the weld is to be made. The metal can be cleaned in a number of ways. If the metal pieces are at all oily they are first dipped in a bucket of lye and then in a bucket of water. If the pieces have any petroleum oil on them, the lye will not clean them, and they must first be wiped down with waste. Sand-blasting and tapping will remove the scale. Any remaining dirt can be forced out into the upset.

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Then the clamps must be set lightly on the pieces, and the contact surfaces must be as large as possible so that there will be good electric conductance. If the contact at the clamps is imperfect the clamps will become heated.

The distance between the clamps varies with the diameter of the metal pieces and also with the kind of metal. In a general way, the distance between clamps is equal to twice the diameter, with iron; is three times as great as the diameter, with brass; and four times, with copper. This difference, of course, is caused by the higher conductivity of copper, which requires the immense volume of 60,000 amperes per square inch of metal.

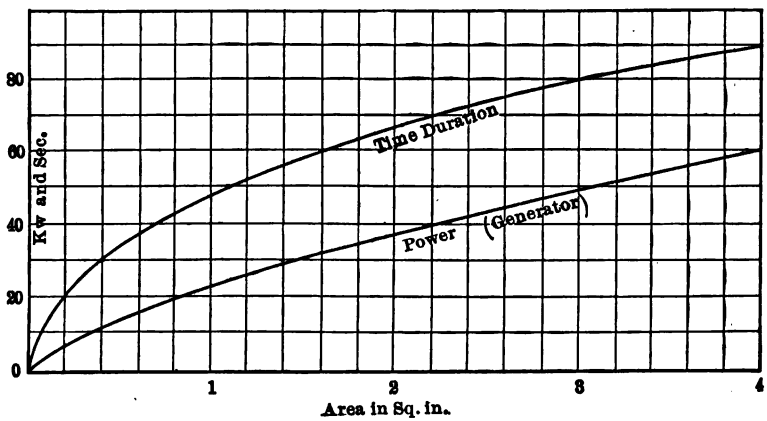

FIG. 22.—Power and time required to weld iron (Standard Handbook for Electrical Engineers).

Some metals are best heated rapidly. Steel, rolled copper, and like metals, which are easily ruined by heat, must be handled with care. They must be heated as quickly as possible; and they must not be overheated, or they will lose their structure. The act of forcing the hot ends together and squeezing the metal helps to maintain the structure and prevent crystallization. Such metals should be worked or hammered while cooling. In welding tool steel the ends are forced together until the overheated metal is all forced out of the joint into the upset. Of course, any scale or dirt is also forced out. When copper wire is welded, it should be upset and then drawn down to the proper gauge. In this way joints of nearly equal strength can be

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made. While quick heating is a good thing, the joint can easily be heated so rapidly that it will be overheated. No metal can stand overheating.

Contrary to common conception, the welding heat is *not* caused by imperfect contact at the joint. The pieces should fit as closely as possible before welding. A poor contact will simply delay the heating.

Rapid welding calls for larger dynamo and welder at greater cost, but the increased efficiency will more than pay for the outlay.

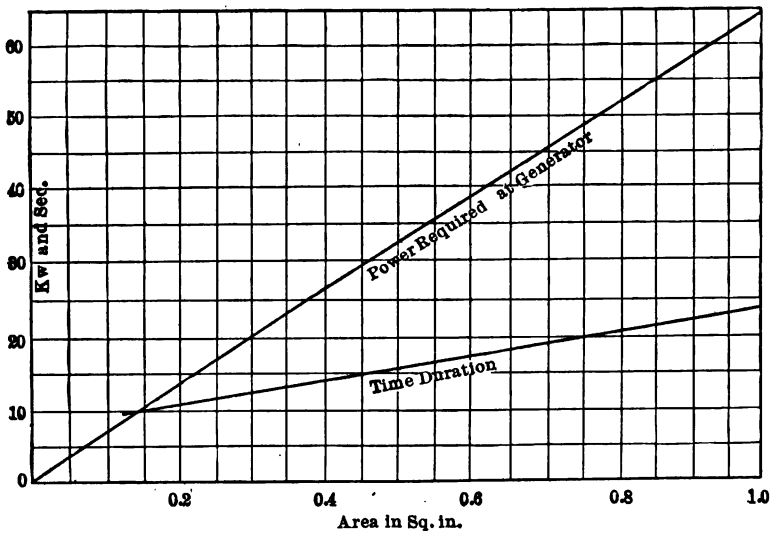

FIG. 23.—Power and time required to weld copper (Standard Handbook for Electrical Engineers).

Seven-horsepower minutes is given as the approximate figure for bringing one cubic inch of iron to welding heat.[1] If the metal clamps conduct the heat away rapidly, from 10- to 15-horsepower minutes are required.

All of the metals of commerce have been welded by this process, both to themselves and to each other. Those metals which are most plastic at welding heat and which have the widest range of plasticity will weld the most readily. Metals which oxidize can be fluxed with borax, sand, sal ammoniac, zinc chlorid, etc., but

[1] *The Engineering Magazine*, Hermann Lemp, Aug., 1894.

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in most cases fluxing is not necessary. The oxid at the contact can be forced out into the upset. Brass is generally fluxed.

Prof. Thomson has in his possession a metal bar of 3/8-inch diameter which is made of nine different metals welded together. However, the Thomson Company does not recommend its machine for cast iron or similar metals of well-defined melting point and which are brittle up to that melting point. Cast-iron pieces can be melted in the welder and their ends stuck together. It is necessary to build up a clay or asbestos form around the joint so that the metal will not run away when it melts. Brass must be treated in the same way. On cooling it will become brittle and crystalline. This is a trouble, however, which is common to all the welding processes. If you are welding a troublesome metal you may as well expect doubtful results. The welding of copper by this process has been a disappointment to some, while others claim complete success for their copper welds. It is evident that the difference between good and bad welds in many instances is due to the skill employed.

Adaptability.—In the last decade the Thomson or similar machines have forced their way into many of the metal trades. In factories where stock welds are made, this process is invaluable. There is a long list of implements that are now welded in the process of making. Those industries which are most benefited are the wagon and carriage, bicycle, tools, wire, chain, pipe and pipe bending, and miscellaneous, which includes angle welding, typewriters, printers' chases, wire fence, tool steel to steel, springs, bands and rings, umbrella rods, etc.

Occasionally the joining of two different kinds of metals or of metals of unequal sizes will call forth the ingenuity of the workman. Copper and brass are frequently welded to iron. When metals of unequal electrical conductivity are welded, the clamps are placed according to the conductivity of the metal. Thus, for copper on iron, the iron clamp would be placed one diameter away from the end of the iron, and the copper clamp three times the diameter away from the end of the copper piece. Copper and iron weld fairly well because their melting points are fairly close and they will alloy at the contact. On account of the great difference in conductivity, however, the iron will become much

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hotter than the copper piece, unless the latter is pointed or whittled down as shown in figure 24.

Another problem has been to join a bar of iron to an iron plate. In this case, the current, under ordinary conditions, would flow off of the surface of the bar on account of the larger area of the plate. The bar would become heated only on the periphery of the end, and the plate would not be heated to redness. To prevent the current from spreading at the junction, a circular channel is cut into the plate at the proposed junction, as shown in figure 25. In a similar way a large bar can be butted on to a smaller bar by cutting or whittling the end of the large bar.

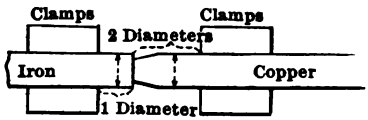

FIG. 24.—Welding iron to copper. Showing adjustment of clamps and shape of copper.

Wire factories can butt-weld their wire ends, thus saving waste pieces and allowing them to make any length of wire specified.

The carriage and bicycle trades have been much benefited by the Thomson process. Frames, hubs, spokes, steps, etc., are welded by this process. In bicycle manufacture, tubes, forks, pedals, crank hangers, mud-guards, etc., are welded. Automobile making is equally dependent on electric welding.

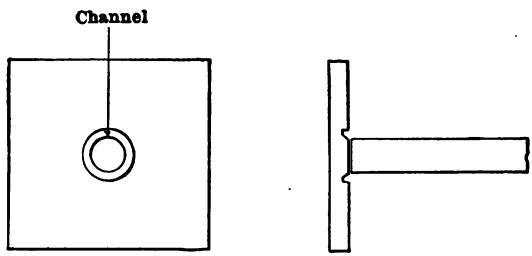

FIG. 25.—Showing how a bar is welded to a plate.

Iron or brass pipe is butt-welded and also heated preparatory to bending. In England wrought-iron pipes are flanged very successfully.

A number of firms weld printers' chases by this method. The bars are held in the hands of the operator, are butt-welded, and

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then right-angled on a frame. The burr or upset is trimmed off on a metal saw and ground even on a wheel.

Chain is being welded by the electrical process; as fast as two links a minute can be turned out on the smallest sizes. In this case some of the current, approximately 10 to 30 per cent.,[1] travels around the ring instead of over the joint. This loss of current is expensive and stands in the way of the general adoption of this

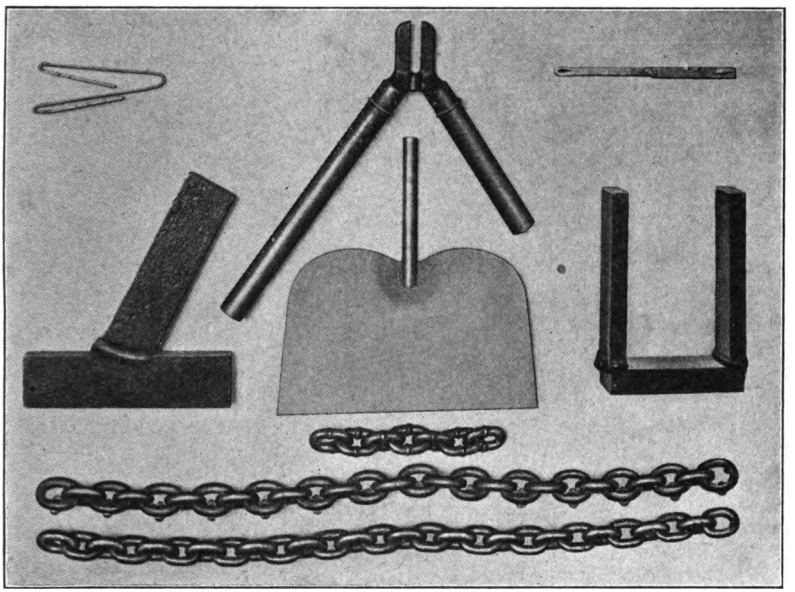

FIG. 26.—Thomson specimens. Type bars, steel to brass; angle weld; bicycle fork; hoe; corner angle weld; chain, two welds; chain showing fin after welding; chain welded and fin removed.

process to chain welding. But it is also claimed that this short-circuiting of part of the current causes the ring to heat sufficiently to bend with ease when the ends of the link are closed. It is claimed that a bar magnet thrust through the link to be welded will largely prevent the current from traveling around the link.

In the welding of hoops and rings this same objection appears. The loss of current is much less for rings of large diameter and

[1] *Iron Age*, W. S. Gorton, July 27, 1905.

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small gauge, and can be further reduced by placing the clamps closer than is the custom.

Electric welding is much used in the manufacture of projectiles and the parts of machine guns. A special high-carbon head can be welded on to a soft-steel projectile cartridge.

Brass heads are joined to steel shanks for use in switchboards.

Garden rakes that were once made of cast iron are now made

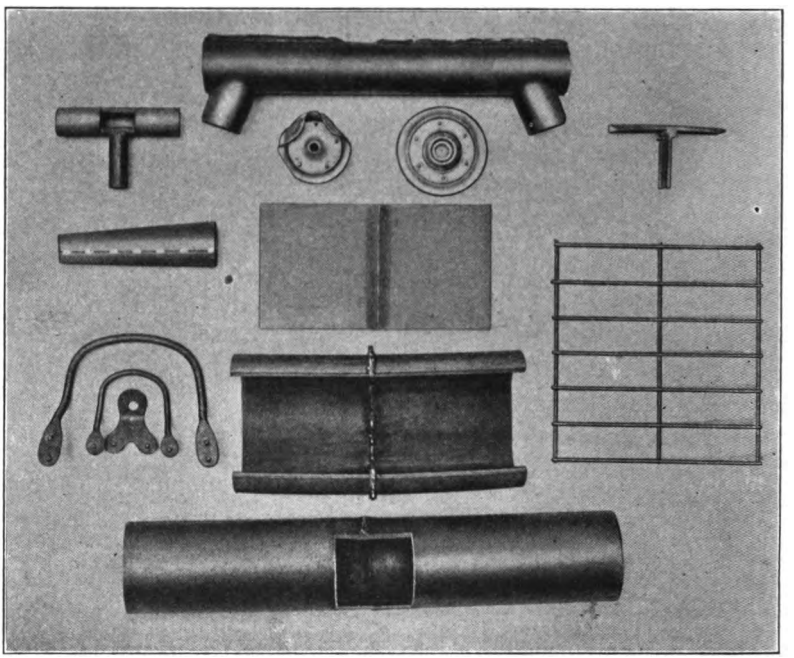

FIG. 27.—Thomson specimens. Tee weld in pipe; furrule; wire handles; bicycle head; sheaves; band saw steel automobile rim; pipe; tee weld; wire mesh.

much lighter and stronger by putting the teeth on a bar. Both teeth and bar are of wrought iron or steel, and are lighter and much stronger than the old cast rake.

Wheelbarrows are made of welded-steel wheels and frames. In the wheels, the rim is welded into a hoop, and the spokes are welded both to the rim and to the hub.

The heads of cap screws are now successfully welded onto the shanks. This allows the manufacturer to cut his thread in the

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hard outer layer of steel. Formerly the screw was cut from a billet of the diameter of the head. The head was harder than the thread which was turned out of the softer metal near the core. It is claimed that the increased strength of the thread and the decreased cost of turning down the shank offset the cost of welding.

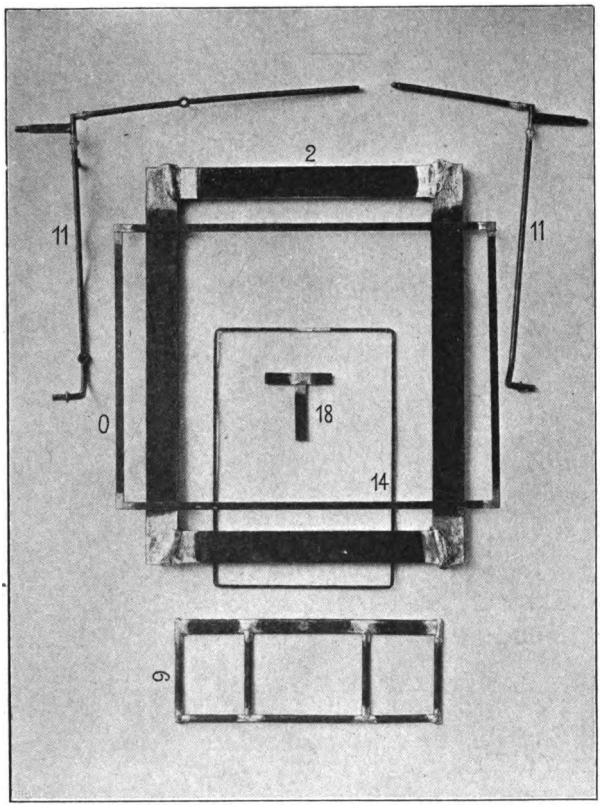

FIG. 28.—Thomson specimens. Printer's chase; carriage rail; bag frame flat; T weld; bag frame on edge; dash frame.

Rail welding was first suggested by Thomson and practised with one of his machines. On account of the importance of electric rail welding and the special apparatus needed, the process will be described in detail.

The most recent application of the Thomson process is to the welding of sheets of metal. Two sheets of steel are lapped

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and welded at regular intervals in points similar to riveting. "The method consists in bringing two pointed electrodes against the two sheets, or prepared sheets with slight projections, by indenting or punching. The current flows through these projections which are pressed down flat on the sheet, effecting the weld. This method is used in interior furnishings of steel railway cars, passenger coaches, steel furniture, sheet-metal ware, etc."[1]

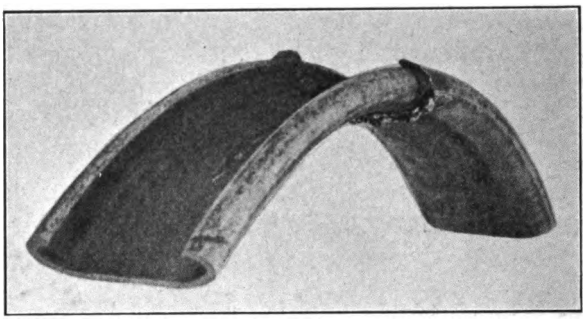

FIG. 29.—Thomson specimen. Automobile clincher rim.

Locomotive Flue Welder.—The Warren Electric Manufacturing Company has furnished the following description of their flue welder, which is especially adapted to the work:

"The flue welder (Fig. 30) operates from an alternating source of electromotive force, and steps the voltage from any convenient line voltage down to from 5 to 10 volts on the weld by means of a transformer enclosed in the body of the welder. The secondary leads from the transformer are connected to two copper contact shoes, which hold the ends of the flues to be welded. These contact shoes have a copper top clamping piece, operated by cam levers, which clamp the flue very securely. The top and bottom members of this clamp are cooled by means of running water. One of these pipe clamps which holds the shorter end of the flue is operated longitudinally by means of a lever, so as to bring the ends of the flues into contact under heavy pressure. One of the foot treadles operates a switch in the primary circuit for controlling the heating of the joint. The second treadle operates a die

[1] Special information furnished by the company.

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which is brought up so as to surround the joint at the time at which compression takes place and prevent an external upset around the pipe at the joint. This die is also water-cooled.

"Owing to the circular form of the pipe, the compression at the joint produces a pressure on the interior portion of the pipe, which increases the density of the metal. This increased density resists the tendency to expand internally, as the metal naturally

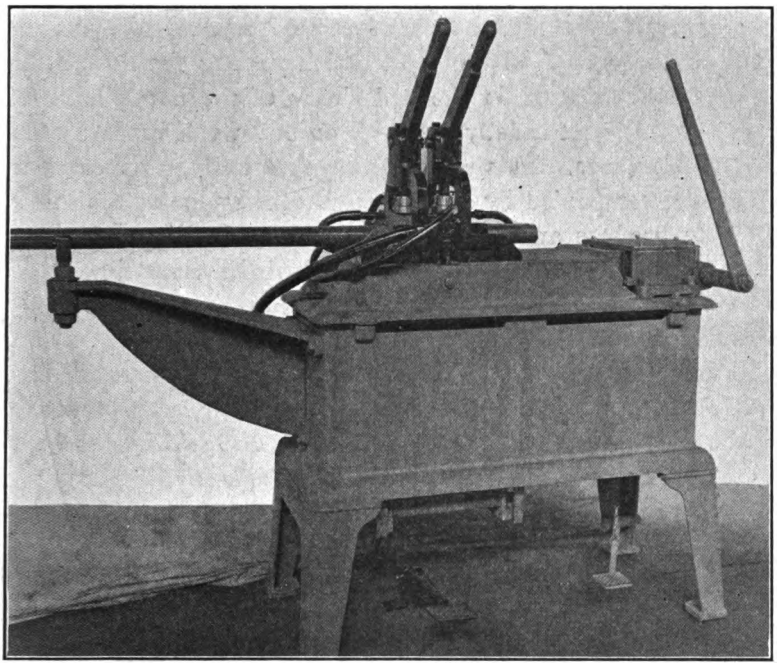

FIG. 30.—Locomotive flue welder.

expands in the direction of the least resistance. It has been found experimentally that there is no tendency whatever to an upset on the inside of the pipe. When the flues are welded without the clamp die, the free flow of the metal is all outward, which produces an exterior upset only.

"The operation of the welder is as follows:

"The two ends of the flue are clamped in place, and then brought into contact by means of the horizontal hand lever. The current is thrown on, and the metal at the joint gradually

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brought up to welding heat. Immediately upon reaching the welding heat, the current is thrown off, and the dies for controlling the form of the weld are brought up into contact with the work by means of the second treadle. A further movement of the horizontal lever is then made so as to produce a very heavy compression of the joint inside of the die. After compression the die is then released, and also the top clamps, so as to relieve the pipe of strains during the cooling of the joint.

"The advantage of this form of welder is a practically smooth joint on the outside of the pipe, which permits the flues after welding to be placed in the end sheets of the boiler without reducing the upset usually met with on butt-welds made by the electrical process. In welding flues electrically, this exterior upset is accompanied by an expansion of the pipe at the joint, so as to produce an annular groove inside the pipe, which is objectionable in boiler flues on account of the accumulation of scale therein. This annular groove is of course entirely eliminated in the flues as welded by this machine."

Rail Welding by the Thomson Process.—The most important single application of the Thomson process has been to the welding of street-car rails. Before 1892, all rail welding was done by the *cast-welding process*. Cast-welding is briefly as follows:

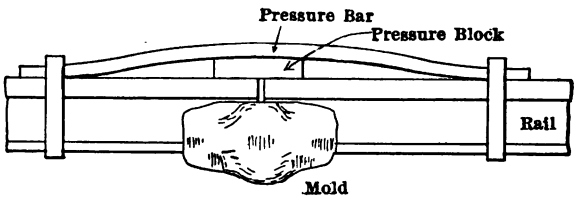

FIG. 31.—Weld and pressure block in place for cast welding.

It is desired to save a piece of track from scrapping, that is weak at the joints, and whose rail heads have been considerably worn. The cast-welder machine consists of two cars. The first car contains the sand blast which cleans all dirt from the rail joint. A cast-iron mold is then clamped onto the joint, and the ends of the rail heads are pressed down by a block which prevents them from springing when the joint is cast (see Fig. 31). The second car is now moved over the joint mold. This second car contains

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the melting cupola—a small, coke-fed blast furnace which melts down a mixture of charcoal iron and assorted scrap until it is at a high temperature. This very hot iron is run into the mold and forms a cast-weld around the heads of the rails. Examination of this joint shows that the cast iron of the joint and the steel of the rail have amalgamated. The cast-weld is still being used, though it has strong opponents. As many as 200 cast-welds can be made per day.

In Los Angeles there are several hundred miles of cast-welded track that are being displaced as unsatisfactory. Only one joint in ten was found to have amalgamated at the so-called weld. The result was a loss of electrical conductivity of from 25 to 75 per cent. The cost per cast-welded joint was given as roughly $7.00 as against $5.00 to $6.00 for the thermit joints which are displacing them. The breakage was said to be about two per cent per annum, and track that was welded in cold weather broke the least. "Sun snakes" were a common occurrence, and were prevented by building the paving close to the rail. No open rail track can be welded, as it will warp and snake.

Recently the electric roads have begun to adopt the electrically welded rail and also the thermit-welded rail (see page 123). Welded rails are a great improvement over those joined by fish-plates and bonded with copper wire, for conducting the current:

1. The conductivity of the weld is as good or better than the unit section of rail. There is no bonding to come loose or leak or be stolen.
2. The rail will last much longer.
3. Welded tracks is smoother riding.

Rails running through city streets are well embedded in the street. If the street paving is not a good conductor of heat and the extremes of summer and winter temperature are not too great, very long sections of track can be welded into one piece without fear of pulling loose at the ends or at any of the joints. A section of 2300 feet has been solidly joined at Holyoke, Mass. It is calculated that the coefficient of expansion of steel in such a climate would cause a stress of about 16,000 pounds to the inch, while the tensile strength of the rail would run well over 40,000 pounds.

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Friction of the pavement against the rail and inertia of the rail prevent dragging, and the expansion and contraction are taken up by the elasticity of the rail. Rails welded with thermit or by electricity are less liable to crack or pull apart at the weld than are cast-welded rails.

The Thomson process was the first process of welding applied to the production of continuous rails on electric railway tracks, and was introduced by the Johnson Company in 1892.

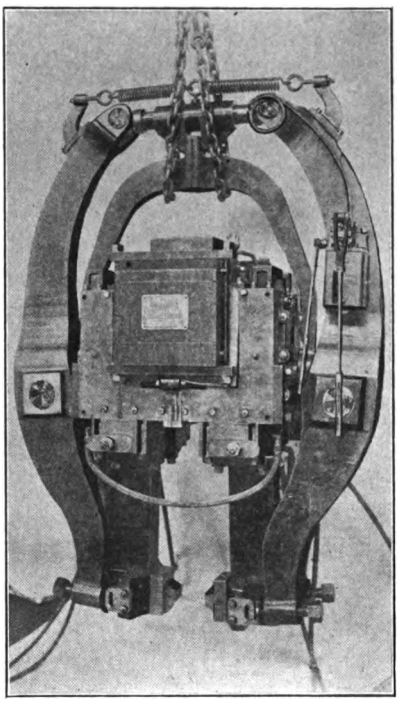

FIG. 32.—Thomson special machine for welding rails in streets.

In 1897, the Lorain Steel Company, successors to the Johnson Company, improved the process and placed it actively on the market. Since that time it has been made use of in almost all the large cities of the United States, and the company found it necessary to double its equipment for this kind of work.

The joint consists of two bars welded to the web of the rail, one on each side. Three welds are made between the bars and the rail, one directly over the ends of the two rails and at each end of the bars. The central weld is made first. In cooling, the contraction of the bars draws the abutting rails together so that no opening remains across the head of the rail.

The apparatus is mounted on four trolley cars, propelled by their own motors. The first car carries a sand-blast apparatus for cleaning the rails and bars. The welder is suspended from a crane projecting from the front of the second car (see Fig. 32). The welder itself consists of a "step-down transformer for supplying current for heating the weld, and hydraulic pressure apparatus

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for supplying a heavy pressure to the portions to be welded." Suitable mechanism is carried within the car for raising and lowering the welder and to swing it from side to side to engage either rail. Coupled to the welder car, the third car carries rotary transformer and regulating apparatus for changing the direct current from the trolley to alternating current. A switchboard with instruments, etc., is also carried in this car.

The fourth car carries two grinder carriages, one suspended over each rail, to smooth down any inequalities that may exist on the head of the rail after the joint has been welded and to produce a true running surface.

The process has been successfully applied to all kinds of rail, both girder and T-rails. Also to the welding of the "third" or conductor rail on elevated and surface lines.

The process particularly commends itself for use in crowded city streets on account of its harmlessness, as it is not affected by dampness and there is no danger of explosions, etc., due to sudden rain storms. The apparatus is practically noiseless in its operation.

An interesting application was the welding of the T-rail on the surface track on the north and south roadways of the Brooklyn Bridge in 1906.

The cost of the equipment makes it more desirable for a railway company to have the welding done for them than to do it themselves.

The apparatus is also made use of for welding heavy copper cables to the rails, either for overhead return or around special work. As the conductivity of the welded joint is greater than the rail, a most perfect system of bonding is thus afforded at the same time with the elimination of the joints.

From ten to twenty welds are made per day by this machine. The breakage is said to run less than 5 per cent., and often not higher than 1 per cent. The machines are leased, not sold, and the cost must accordingly be figured on the rental, power, and labor in calculating the cost per joint.

Electric Resistance Heater.—Besides its use as a welder, the machine may be used as a preheater of metals to be brazed or bent. It will sometimes be preferable to braze or solder a

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joint, when the two metals cannot be allowed to lose their shape or have any of their substance pressed into an upset: the welder can then be used as a preheater. The current would be regulated to bring the metals to a slightly lower-than-welding heat and keep them at this heat. In brazing brass, this is the best-known method of preheating, because a torch preheater always burns out some of the zinc in the brass and oxidizes the copper.

The Thomson welder may be used to anneal spots in armor plate. This is done by connecting the positive to the armor plate and pressing the negative clamp against the spot to be annealed.

Tests.—In general, tests of electric welds show that from 75 to 95 per cent. of the original strength of the metal is reached. In cases where the upset is not cut off, the strength can be increased above 100 per cent. Welds of low-carbon steel and low sulphur-and-silicon iron, if well made and worked or drawn after working, will approximate 100 per cent. in strength.

It is sometimes asked if the electric current does not damage the metal. Electric welding is no more harmful to the metal than any other process. In fact, the control of the heat is so exact and overheating and reheating so seldom happen, that electric welds run uniformly high in tensile and elastic strength. A "burned" weld seldom occurs—the oxid at the joint is forced out into the upset and ground off. It may be emphatically stated that the electric-resistance welds are the best yet made. As an instance, such a misused and overstrained utensil as a printers' chase seldom gives at the weld.

Sir Frederick Bramwell[1] states that 1 1/8-inch round bars can be welded in 2 1/4 minutes with an average tensile strength of 91.9 per cent., against four minutes' time and 89.8 per cent. strength when smith-welded.

The results of a series of tests of electrically welded metals carried on at the Watertown Arsenal[2] may be abridged as follows:

Twenty-nine broke at the weld.

Seventeen within 2 inches of the weld.

Eleven within the range of moderate heat.

Two near the grips.

[1] "Elec. Engineering Formula," p. 673.

[2] *Transactions of the American Society of Mechanical Engineers*, 1889, p. 97.

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Welds of wrought iron were 5 to 10 per cent. below unit strength; fracture fibrous or slightly spongy.

Welds of steel were from 50 to 80 per cent. less than unit strength.

Copper welded at 5 to 10 per cent. less than unit strength.

Steel welded to wrought iron at about the strength of the iron.

Brass gave an uncertain weld with wrought iron and had a strength at the weld of 8 1/2 to 16 1/2 tons to the inch.

Steel welded with German silver with a strength of 20 tons to the inch.

Some welds of steel were about unit strength and some of iron were above unit strength.

A number of these bars had upsets, however, and the upset does not seem to have increased the strength very much.

When electric welding was first tried out there was serious complaint that the welds were burnt, spongy, and weak. This was due to the fact that the metals were melted together and were not worked. The welding machines with automatic swage blocks prevent crystallization at the weld, as does also hammering after welding. The weld is still liable to be weak on the edge of the heating radius. Many joints that will hold at the weld will break an inch either side because the heat has destroyed the properties of the metal.

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PART III—HOT-FLAME WELDING

THE OXY-ACETYLENE PROCESS

General.—Lest the variations in practice and the variety of apparatus about to be described should prove confusing, it is well to state that the oxy-acetylene welding process depends on the high heat of combustion of oxygen and acetylene. The apparatus primarily consists of:

1. Apparatus for storing or generating oxygen.
2. Apparatus for storing or generating acetylene.
3. A burner or blowpipe, with leading tubes, for the combustion of oxygen and acetylene.

This is the simple story, of which there are many details. The advantages and limitations of the processes here described are as follows:

1. The apparatus is fairly light, easily portable, and can be installed permanently.
2. For repair work, the cost is light and the results satisfactory.
3. On account of the intense heat of the flame, any substance or metal can be melted locally at once.
4. The high heat of the flame represents a limitation in so far as it is difficult to adjust and dangerous to use unless the operator knows his business.
5. The weld, being a melt-weld, is subject to oxidation and carbonization from the flame, and to crystallization on cooling.

The merits of the oxy-acetylene process greatly outweigh its possible faults. There is no process that will compare with it for welding job work of all kinds of metals and for repair work.

The present use of the oxy-acetylene flame in welding and autogenous soldering is the outcome of the discoveries of many experimenters. It is a step beyond the oxy-hydrogen process: the flame has an opproximate temperature of 3500 deg. Cent., while the oxy-hydrogen is about 2250 deg. Cent. But this high

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heat and the explosive nature of acetylene complicate the problem. Special apparatus had to be devised; special instructions worked out for its use in practice. As one writer states, its practical value was at first overestimated by those interested in it. And when obstacles arose their ardor was checked and the process suffered a temporary relapse. At the present writing, however, the oxy-acetylene process is in a state of rapid development, and it has passed the critical stage. It is a recognized repair and welding process. It is being used to weld or solder almost all the metals, both to themselves and to one another; it is also used to cut through steel and iron plate, bars, etc., with six times the rapidity of a saw.

There are several items in the apparatus for this process that have advanced its use. One of them is the compounds for producing oxygen *in situ* and at less expense than by the ordinary electrolytic process. The Industrial Oxygen Company of New York sold until recently a powder called "Epurite," probably sodium dioxide, which produced oxygen when wet with water. In 1906 the Industrial Oxygen Company withdrew this compound and advanced a second, called "Oxygenite." Oxygenite necessitates special combustion, cleaning and storing tanks, but cost of these is small in comparison with the cost of an electrolytic plant, and brings it into competition with the storage oxygen made by the electrolytic and liquid-air processes.

The Davis-Bournonville Company have recently adopted the potassium-chlorate method of generating oxygen in cases where tanked oxygen is inconvenient. As with Oxygenite, special tanks are required for generating, washing, and storing. Their oxygen compound is not combustible and requires the external heat of a gas flame. Fuller particulars of these two chlorate processes are given on pages 86 and 87.

Since 1880 industrial oxygen has been sold in increasing quantities by the firms using apparatus for the electrolysis of water. France and Germany have been specially active in projecting methods. The processes of Schuckert, Garuti, Schoop, and Schmidt are worthy of mention. In late years oxygen obtained by the Linde liquid-air process has come into competition with electrolytic oxygen. It is most largely used in this country, while

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the company claims to supply 90 per cent of the world's demand for oxygen.

Acetylene was discovered in 1837. It was first recognized as a valuable illuminant, more especially in France, where it is used by hundreds of municipal plants at the present day. France is also foremost in oxy-acetylene welding inventions, among the most important being those of Fouché.

Acetylene can now be had in two forms: stored acetylene in steel cylinders, such as are used for carbon dioxid; and calcium carbid, which produces acetylene when wet with water, according to the formula—

$$CaC_2 + H_2O = C_2H_2 + CaO.$$

Stored acetylene was originally a dangerous commodity. It was liable to explode under pressure. The railroads objected to handling it. So the acetylene producer, calcium carbid, held the market. The gas was generated at the place where it was to be used and kept in a tank under less than 10 pounds' head. In 1897, the acetone-absorption process was patented, and since then stored acetylene has been in active competition with the carbid (see p. 92).

At the present writing a repair shop desiring to set up an acetylene welding department is offered a number of alternatives:

1. The acetylene can be bought in storage tanks or it can be generated from the carbid.

2. The oxygen can be bought in storage tanks or it can be generated from Oxygenite or by the other chlorate method.

3. Oxgyen can be dispensed with and atmospheric air substituted. For this purpose a pressure pump and air gasometer are needed. Under the second head it might be added that oxygen could be produced by the electrolysis of water. But this would require a large, costly outfit, running up into thousands. Under the third head, oxygen air and acetylene are sometimes used in a three-way burner.

Apparatus and Gases.—*The Torch.*—The first oxy-acetylene torch was invented by Mr. Edmond Fouché, who at the time was general manager of the Campagnie Française de l'Acetylene dissous.

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As they were using compressed acetylene in acetone, it was very easy with acetylene under pressure to get the proper mixture when used with oxygen under pressure.

A couple of years later Fouché went with another company, which was controlled by Javal. But as they were not handling compressed acetylene, but only generators using gas under a normal pressure, Fouché went ahead and devised a new oxy-acetylene burner under the principle of an injector, which with the oxygen under pressure coming from a small tube into a larger, would produce a suction, by this absorbing acetylene in enough quantity to produce a very hot flame. So this is where the first two torches originated—high- and low-pressure.

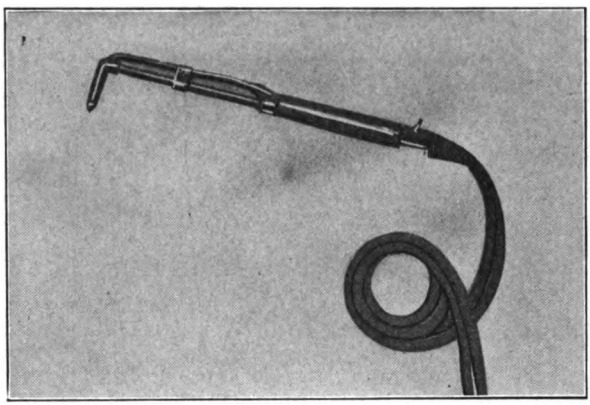

FIG. 33.—Low-pressure torch for oxy-acetylene. Industrial oxygen company.

There is a certain defect in both these torches. The high-pressure torch mixes in the long tube as the two gases are forced together near the handle, and when the tip of the burner gets overheated in case of a flash back, you get a back fire in the whole length of the tube; in which case, if the operator is not quick in cutting off the flow of gases, he runs a chance of melting part of his torch. As for the low-pressure torch, the defect is in depending entirely on the suction made by the injector, which very often does not carry enough acetylene gas, making an oxidizing flame which prevents the metal from uniting properly and making the weld very weak.

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The house of A. Boas Rodrigues & Company, of Paris, after looking over both systems, went to work to devise a third torch, which as far as possible would remove some of the objections of the high and low pressure. By making a medium-pressure injector type of torch, having the acetylene under at least 3 pounds' pressure or a little more, they could force in a surplus of acetylene so as to remedy the defect of the low-pressure system, which depended only on the injector.

Moreover, back-firing was not troublesome in this medium-pressure torch, because the gases were mixed an inch from the nozzle. If the torch back-fired, the operator could tell at once by the roaring sound. If he did not turn off the flame at once, the

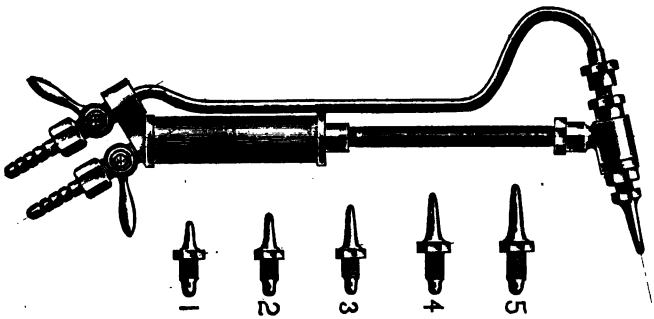

FIG. 34.—High-pressure oxy-acetylene torch and replaceable tips (Davis-Bournonville Company).

tip would be burned, but not the torch. The tip could be unscrewed and replaced.

The present low-pressure torch (Fig. 33) also mixes its gases a short distance from the tip of the nozzle.

The nozzles of all oxy-acetylene torches suffer in time from the intense heat of the flame. Constant back-firing, caused by holding the torch too close to the work, will soon burn out the tip. Pieces of melted metal will get in the tip, and should be removed carefully. The burner is a very sensitive tool.

The up-to-date torch is a handy affair with cocks at the handle end to turn the gases on and off and a small detachable tip or burner at the nozzle end. The gases are mixed near the orifice in the low-pressure torch. In the high-pressure torch the gases are mixed in the tip (Fig. 35). In both torches the acetylene is

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first passed through a packing of asbestos, wire gauze, etc., with handle which prevents a flash back into the generator, on the principle of the Davy lamp. The torches are in several standard sizes, each with five or six graded detachable tips. An extra oxygen tube can be clamped on the burner when used for cutting metals. Special cutting torches (Fig. 36) are now made.

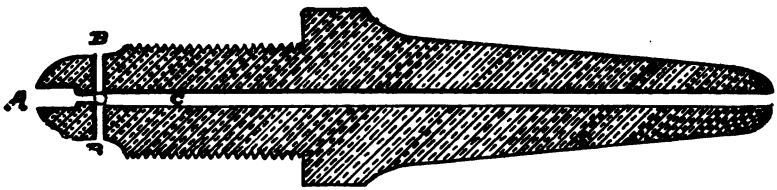

FIG. 35.—Diagram of replaceable tip of high-pressure torch (Davis-Bournonville Company).

A new cutting head is screwed into the torch head. The pure oxygen jet flows through the center and in front, and behind this are two small heating flames, four in all. With this torch it is possible to cut in any direction.

To summarize, there are at present in use in this country three torches:

1. The original Fouché torch, improved, in which the gases are mixed as they enter the haft.

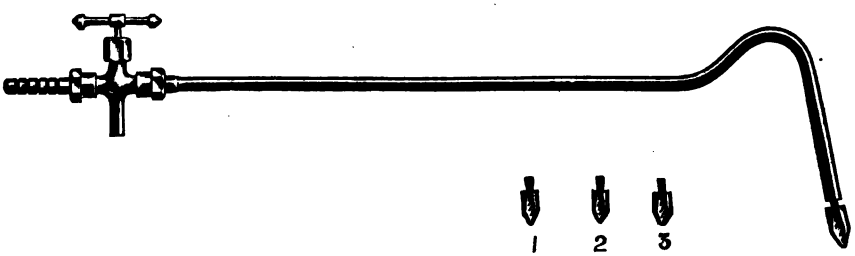

FIG. 36.—Cutting torch attachment (Davis-Bournonville Company).

2. The low-pressure torch (also invented by Fouché) in which the oxygen injected under pressure draws acetylene with it (Fig. 33).

3. The high-pressure torch (French medium pressure) with acetylene up to 15 pounds and oxygen stepped down from 120 atmospheres to one or two atmospheres (Fig. 35).

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Each torch claims its advantages, and to number them would be to simply give the talking points of the competing firms, without effect.

The Low-pressure Torch (The Linde Air Products Co.)

		Oxygen	Acetylene		
Blow-pipe No.	Approximate thickness of sheet or plate, inches	Approximate consumption cubic feet per hour	Approximate consumption cubic feet per hour	Foot run per hour	Approximate cost per foot run, including labor
3	$\frac{3}{64}$	4	$2\frac{1}{2}$	30	$.012
4	$\frac{3}{32}$	6	$3\frac{3}{4}$	21	.021
5	$\frac{1}{8}$	10	6	15	.037
6	$\frac{3}{16}$	16	10	6	.125
7	$\frac{1}{4}$	25	15	4	.256
8	$\frac{3}{8}$	36	22	3	.456
10	$\frac{1}{2}$	45	28	2	.827

NOTE—For copper plates larger blowpipes are required than for steel plates of corresponding gauge.

Another authority estimates 25 per cent. additional of each gas for the same thickness of plate. The high-pressure torch uses about the same volume of gas, with the oxygen and acetylene in the proportion of 1.28 to 1.

Miscellaneous Apparatus.—Besides the apparatus already touched on, there are pressure-reducing valves on all of the pressure tanks. These may be set by the turning of a handle to any constant pressure required; the dial shows the pressure (Fig. 38).

Both systems have water valves in both gas tubes, to prevent the back pressure of either gas in case of accident. For instance, in the low-pressure system, if the oxygen should accidentally flow back into the acetylene tube, it would get as far as the valve which would let it out into the air instead of into the acetylene tank. This prevents explosions. "The action of hydrolic back-pressure valve is apparent from figure 37. The cocks on the acetylene pipe from the gas holder is connected to the inlet at B, and

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the acetylene pipe leading to the blowpipe is connected to the outlet C. D is a priming cup through which water can be poured into the chamber until it overflows at the cock F. The cock on the service line at B must be closed while the chamber is being filled with water. When water shows at the cock F, it must be closed and the cock at B opened. The valve is then in working order.

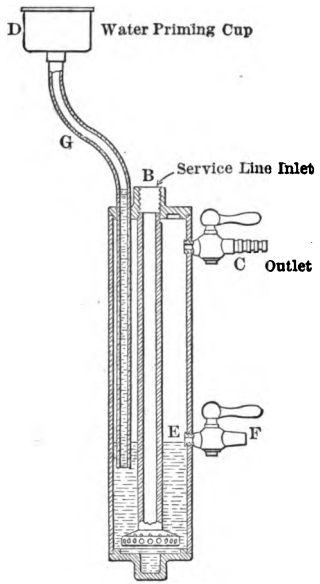

FIG. 37.—Diagram of safety water seal, to protect the acetylene supply (the Linde air products company).

"The pipe G, leading from below the seal at E to priming cup, is made of sufficient length to hold a column of water equal to the pressure in the acetylene holder, which would be equal to not less than 12 inches of water, and in no case should exceed 20 inches.

"In cases where two or more blowpipes are worked from the same acetylene supply pipe, a separate back-pressure valve should be employed for each welding station."

The companies furnish twenty or more feet of hard-rubber tubing, wire-wound.

Goggles for the eyes are advised, both to protect them from the bright light and from flying sparks.

Electrolysis of Water.—When water is decomposed by electrolysis, it gives 2 volumes hydrogen, 1 volume oxygen.

The electrolyte is a dilute solution of sodium or potassium hydroxid; oxygen rises from the positive and hydrogen from the negative. If the gases are collected as mixed oxygen and hydrogen in the gasometer, it is called *detonating gas.* This is the gas that was first used in the oxy-hydrogen blowpipe (see page 117). Detonating gas is handy for blowpipe work, but it is dangerous. It is the most readily combustible mixture of the two gases, and if the torch backfires there will be an explosion. To prevent

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this a safety water-seal was introduced in the leading tube, or the blowpipe handle contained a chamber packed with fine rods or gauze or asbestos wool to imitate the idea of the Davy safety lamp.

The railroads will not handle detonating gas, and it is not manufactured except privately. In the electrolysis of water nowadays a diaphragm placed between kathode and anode separates the gases. Of these gases the oxygen is of the greater commercial importance.

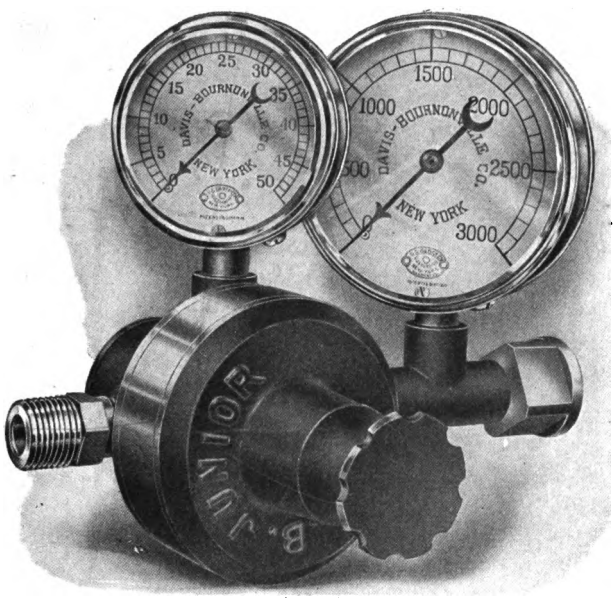

FIG. 38.—Oxygen constant-pressure regulator.

Oxygen is colorless, odorless, non-poisonous, and supports combustion with hydrogen, acetylene, producer gas, etc.

Since 1880 rapid progress has been made in the manufacture of nearly pure oxygen and hydrogen by the electrolysis of water. Abroad, it is the main source of these two gases, especially since 1900. In America there is but one electrolytic industrial plant. The Linde oxygen practically controls the market.

Among the successful commercial processes in Europe are

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those using the patents of Schmidt, Schuckert, Garuti, Schoop, and Hazard-Flamand. The Schuckert apparatus is as follows:

"It consists of a cast-iron tank, containing a number of cast-iron electrodes in various chambers separated by diaphragms, extending from the top downward about three-fourths the depth of the cell, the gases being conveyed through a pipe system to separators, whence the wash-water is returned to the electrolytic cells.

"The electrolyte is a 20 per cent. solution of caustic potash. The cells are embedded in a sand layer about 2 or 3 inches in thickness, arranged to protect the apparatus from heat radiation, the temperature of the electrolyte being maintained at about 75 deg. Cent. This is said to be the most satisfactory temperature, as the lowest voltage is required at this temperature for decomposing the electrolyte. The pressure is from 2 to 3 volts, and the various cells are connected in series very much the same as a battery of accumulators. The hydrogen and oxygen gases when generated at the electrodes are conducted through pipes to separate gasometers or tanks for storage."[1]

From 97 to 99 per cent. oxygen is claimed for this plant, which is that of the Schuckert Co., Nürnberg, Germany.

Another process, the Hazard-Flamand is also described in detail in *the Electro-Chemist and Metallurgist*[2] of the British Faraday Society. The table of relative outputs at different current values is given below.

The Hazard-Flamand Cell

Volts applied at voltameter terminals	Current in amps.	Yield of O_2 grams per hr.	Yield of O_2 grams per kw.-hr.	Per cent. of theoretical energy efficiency (213.07 grams per kw.-hr.)
2.1	243	72.0	141.7	66.5
2.3	265	79.0	129.6	60.7
2.8	323	96.2	106.3	50.5

[1] *Electrochemical and Metallurgical Industry*, F. C. Perkins, May, 1906.
[2] *Electro-chemist and Metallurgist*, June, 1904.

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"In considering the fourth and fifth columns, it must be born in mind that hydrogen is also liberated, of double the volume, but of 1/8 the weight. In other words, with an e. m. f. of 2.1 volts, each voltameter produces 1.8 cu. ft. of oxygen per hour and 3.6 cu. ft. of hydrogen, of the respective approximate weights of 72.0 and 9.0 grams."[1] The article goes on to state that while 2.1 volts is theoretically most efficient, 2.4 gives best practice. The oxygen is 99 per cent. pure and the hydrogen in proportion.

Manufacturers of electrolytic gases claim that their oxygen is much purer than that of other processes. Oxygen by the chlorate process is contaminated with carbon dioxid, often over 10 per cent. Liquid-air oxygen contains from one to five per cent. nitrogen. The impurities of electrolytic oxygen are a few per cents. of hydrogen, a little chlorin, and water vapor. In laboratory determinations these impurities sometimes determine which kind of oxygen shall be used. For welding and soldering, the gases should be pure for the sake of keeping harmful impurities from burning into the metal.

The first cost of installation of an electrolysis plant is very great and may reach as high as $25,000, exclusive of maintenance cost. For this reason very few industries would find it worth while to install such a plant for welding purposes. In Europe these installations are most often separate concerns for the manufacture and sale of stored oxygen and hydrogen.

For further information about electrolysis of water the reader is referred to "The Electrolysis of Water," by Engelhardt, translated by Richards, 1904.

Storage Oxygen.—Oxygen can be bought in steel cylinders. There are two industrial processes at present for making oxygen. It can be drawn from the atmosphere by the liquid-air method or it can be produced by the electrolytic decomposition of water. This latter method to which there are many variations is largely used in Europe.[2] The patents for the former method are owned and operated under, in this country, by The Linde Air Products Company.

By the Linde process the atmosphere is compressed by a

[1] June, 1904.
[2] "Electrolysis of Water," Victor Engelhardt, 1904.

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double-stage pump up to 1800 pounds. This compression raises the temperature 1 deg. Fahr. for every 2 atmospheres pressure. The compressed air is cooled by ice and salt (for small plants) or by ammonia (for large plants). If this air, then, at 1800 pounds and about 15 deg. Cent., be expanded, the temperature will drop considerably. If some is expanded on the outside of a cylinder under the same pressure, the air in the cylinder will be lowered in temperature and will liquefy because it is under pressure. Liquid air consists of approximately 80 per cent. nitrogen, critical temperature,—149 deg. Cent.; and 20 per cent. oxygen, critical temperature,—119 deg. Cent. The oxygen is then separated by fractional distillation similar to the rectification of spirits.

Storage oxygen can be obtained in cylinders of sizes and weights shown in the following table:

Oxygen in Cylinders (The Linde Air Products Co.)

Contents in cubic feet	Approximate weight in pounds (empty)	Price of cylinder with valve	Rent per week after the first month
5[1]	6	$ 6.50	
25	38½	8.50	$0.50
50	62	12.00	0.75
100	132	20.00	1.00

The oxygen is under pressure of 120 atmospheres. It is guaranteed 95 per cent. pure, the residue being nitrogen. As nitrogen is inert and not in sufficient quantity to absorb heat or retard action, its presence is negligible.

These tanks may be rented and the oxygen bought or both gas and tank bought outright. In either case the company will recharge them, subject to certain conditions. On account of the very high pressure, the cylinders are annealed at least once in four years, and are carefully inspected and labeled on charging. Each tank must have reducing valves and, when in use, pressure gauges. The railroads receive them charged as second-class

[1] This size of cylinder cannot be hired.

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merchandise, and discharged as fourth class, and also on account of the pressure.

The factor of safety is large with these tanks, but nevertheless they must be kept in a cool place. In the heat of the direct sun's rays the pressure will greatly increase.

The present price of this stored oxygen is from two and one-half to four cents, depending on the quantity bought. Rent is charged on the tanks after the first month. This is exclusive of transportation. The advantage of having a large volume of oxygen, in small bulk, when a generator is unhandy or expensive, is very apparent. The principal disadvantage is the possibility of leakage, which is a variable factor. Datum is not at hand, but it is common opinion that tanked oxygen is at least five per cent. purer than that produced by the chlorate process.

Oxygenite.—"Oxygenite" is the name given to the oxygen-producing powder sold by the Industrial Oxygen Co. Its main constituents are potassium chlorate and manganese dioxid in the probable proportion of 100 to 13 by weight. To this is added a small percentage of carbon in the form of lamp-black, to support and assist combustion. The powder is a fine gray sand in texture; wetting it will not diminish its oxygen-producing ability, though it will cause it to cake and harden. It is accepted by the railroads at the merchandise rates and is safe to handle.

One pound of Oxygenite when ignited with a match burns with the production of oxygen and carbon dioxid, producing about 4 cubic feet of the gas. The oxygen is produced according to the reactions

$$2KClO_3 + \text{heat} = 2KCl + 3O_2 \text{ and } 3MnO_2 + \text{heat} = Mn_3O_4 + O_2.$$

The principal function of the manganese dioxid is to reduce the temperature of occlusion and to prevent the chlorate from melting and flashing. As a good portion of the oxygen is consumed by the carbon, carbon dioxid gas forms a large percentage of the resultant gas. This is washed out of the gas by passing it through a solution of sodium or potassium hydroxid. The reaction continues up to 200 pounds' pressure and takes less than three minutes.

Figure 39 is a diagram of the apparatus in position. It consists of a combustion chamber, a washing tank in which pebbles

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are drowned in the caustic solution, and a gasometer. The function of the pebbles in the washing tank is to cause the gas that is let in at the bottom to work its way more slowly to the top and to break up the bubbles. Less caustic solution is needed, and such a washer takes the place of three washers in which the solution is free.

This process has its own special advantages, though it is not cheap. Oxygen can be generated on short notice and at high pressure without the aid of a gas flame for heating nor of a pressure pump.

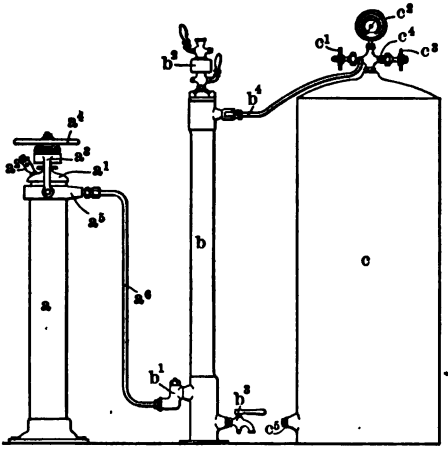

FIG. 39.—Oxygen apparatus using oxygenite (Industrial Oxygen company).

Oxygenite is at present selling at $15 per 100 pounds. Since each pound is claimed to produce 4 cubic feet of oxygen, the cost per cubic foot, exclusive of apparatus, operation, and incidental costs, would be four cents. Storage oxygen is selling at present above three cents per cubic foot. While the final cost of using Oxygenite is probably greater than storage oxygen, it is able to compete with the latter, because it is safer to handle and can be kept indefinitely.

Oxygen from Chlorate.—The Davis-Bournonville Company has recently added to its line apparatus for the production of oxygen. The method is similar to the Oxygenite process, but the oxygen mixture is not combustible; it must be heated exter-

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nally with a gas flame. This mixture is composed of potassium chlorate, 100 parts, and manganese dioxid, 13 parts; both should be fairly pure to insure a gas of 97 to 98 per cent estimated purity after three scrubbings.

Figure 40 shows the apparatus in position. The oxygen mixture is charged into the retort, which should be as full as possible to exclude ordinary air. The retort is heated with a slow gas flame so that the generation is regular; as the heating proceeds the flame is raised to drive off the last of the oxygen. The oxygen generated passes through three washer tanks filled with sodium hydroxid solution, and then into a gasometer. From the gasometer the gas is compressed by a two-stage compressor into pressed-steel cylinders, at a pressure of 300 pounds to the inch. This for the reason that considerable pressure is needed to make a good jet flame, especially in cutting metals.

This method of generating oxygen takes more time than the Oxygenite process; and it necessitates a compressor pump while the latter does not. The advantages claimed for it are: that there is little oxygen lost when the retort is recharged, because the pressure is low in all of the chambers; that loss from leakage is much less; that the bubbles of gas being much more expanded in passing through the hydroxid solution are washed much more thoroughly.

One writer[1] estimates the cost of the oxygen mixture, when made from fairly pure chemicals, at eight cents a pound. One pound producing 4 to 4 1/2 feet, brings the cost of the oxygen to about 2.25 cents a cubic foot. This is exclusive of freight and operating charges.

Oxone.—Very pure oxygen can be generated on a small scale by wetting sodium peroxid.

$$4NaO + 2H_2O = 4NaOH + O_2.$$

The Oxone idea is a recent development of an old method. The sodium peroxid in fused lumps is delivered in hermetically sealed cans to protect it from the moisture. Each pound of Oxone produces over 2 feet of the gas, at a price of from 13 to 20 cents a foot.[2] The generator (Fig. 41) is made by the Nel-

[1] *American Machinist*, Henry Cave.
[2] Special Information.

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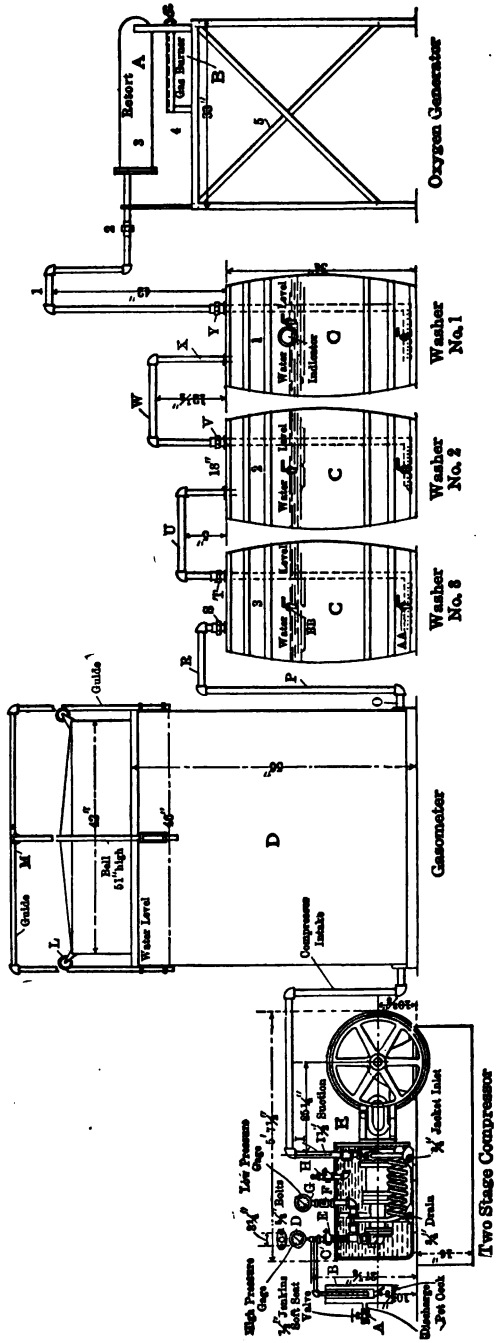

FIG. 40.—Diagram of oxygen generator (Davis-Bournonville Company).

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son Goodyear Company and sold by the Roessler & Hasslacher Chemical Company.

To make oxygen several holes are punched in the top and bottom of the can and it is placed in the generator. The generator is filled with water to the mark, closed and the needle

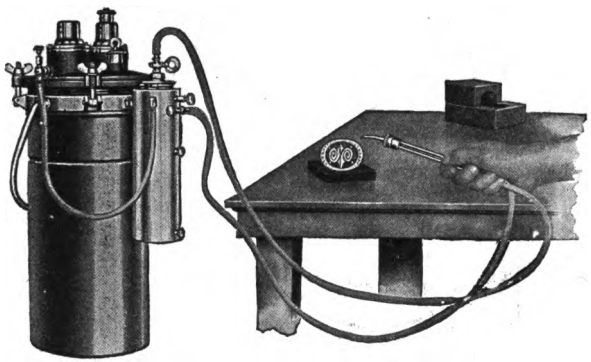

FIG. 41.—Oxone oxygen generator (the Roessler and Hasslacher Chemical Company).

valve opened. Opening the valve lets water in on the Oxone, and oxygen begins to come off. It is claimed to be 99 per cent pure; the trace of water vapor is removed by washing, and the delivered gas is then practically pure. The safety valve of the generator is set at five pounds and the delivery valve at three.

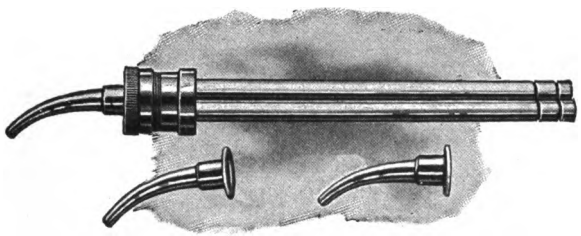

FIG. 42.—Oxygne burner (the Roessler and Hasslacher Chemical Company.)

Closing the needle valve stops the generating. Soda lye is the by-product. In cleaning out the generator be careful not to get the strong lye on the hands nor clothing.

This oxygen is expensive, very pure, and the apparatus easily

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portable. Hence it can be used to make gas for reinforcing the air in submarines or under-ground or under-water workings and by jewelers, dentists, assayers, and silversmiths. For burning this oxygen the company furnishes a special torch (Fig. 42). The other gas of combustion is sulfuric ether; or acetylene, gasoline vapor, or coal gas can be used. The oxygen-ether flame is ideal for jewelers and dentists. Figure 43 shows a handy furnace for melting down metals.

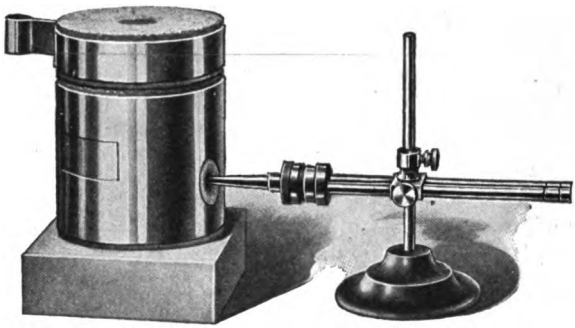

FIG. 43.—Oxone furnace for dentists and jewelers (the Roessler and Hasslacher Chemical Company).

Acetylene.—Acetylene is a heavy, combustible gas with a strong odor, and was first made by Davy in 1837. It is produced by the reaction between water and calcium carbid according to the formula—

$$CaC_2 + H_2O = C_2H_2 + CaO_2$$

The principal impurities of the freshly generated gas are ammonia and hydrogen phosphid and sulphid. These are removed by washing the gas in different solutions which will react upon these gases.

Acetylene is endothermic. So that the great heat of its combustion is the sum of its endothermic factor and the factor for carbon monoxid or dioxid. For this reason acetylene burns with tremendous heat with oxygen. The intense white light of combustion in air is attributed to the nascent carbon particles.

Mixed with air, acetylene is explosive between the range of 2 per cent. gas, 98 per cent. air; and 49 per cent. gas, 51 per

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cent air. This is a very wide range and makes the gas a troublesome one unless used with care. The odor, which is attributed to a small proportion of hydrocarbons, is offensive, but helps to detect leakage. Though there are instances of asphyxiation by this gas, it has been shown that pure acetylene is not a poisonous gas.

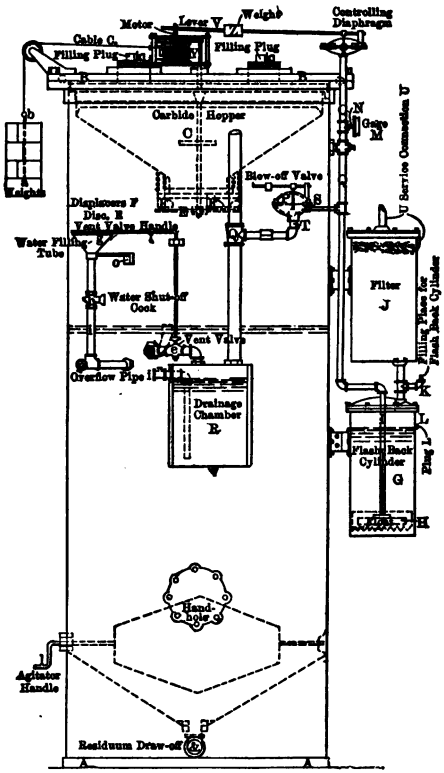

FIG. 43*a*.—Diagram of carbid-feed acetylene generator. (Davis Acetylene Company).

The Acetylene Generator.—In repair shops, where acetylene will be needed continually for the work at hand, it is best to install an acetylene generator. One of the types approved by the underwriters should be selected. It should be placed in a separate shed outside of the shop. This will safeguard the workman and the building in case of accident. Nowadays, however,

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acetylene can be used with perfect safety, provided there is ordinary good sense employed in the installation and use of it.

There are two general types of generators: one in which powdered or granular calcium carbid is fed into water, the other in which water is dropped upon the carbid. The reaction gen-

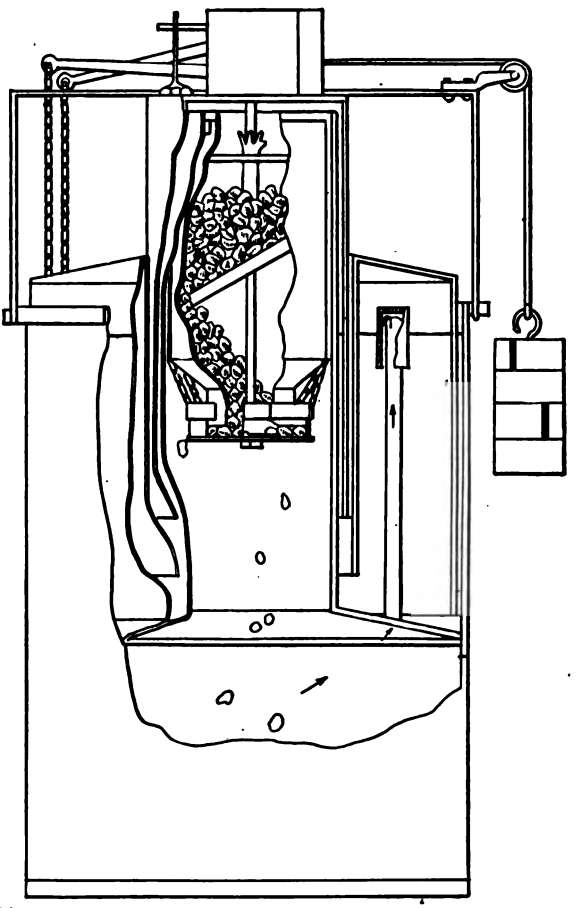

FIG. 44.—Diagram of hopper and feed mechanism. Davis carbid-feed acetylene generator.

erates considerable heat. This is the element of danger. For this reason, perhaps the safer generator is the style first named, in which the carbid would be quenched in water while giving off the gas. One part of carbid will boil six parts, by weight, of

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water. Furthermore, water-feed generators give off gas long after the water is stopped, and carbid-feed only for a short time.

Some carbid contains phosphates which are decomposed with the formation of hydrogen phosphid. This gas, which comes over with the acetylene in small quantities, is said to have a bad effect on the metals to be welded. While tanked acetylene has been cleansed of both hydrogen phosphid and sulphid, the generator acetylene is not. It is important to use in the generator a carbid that is quite pure chemically. The presence of small quantities of phosphorous can be easily told by the white smoke it adds to the acetylene flame. Sulphur cannot be so easily detected.

One pound of lump carbid gives 4 1/2 feet of gas. One pound of *ground* carbid only 4 feet,[1] due to previous decomposition. At this writing the cost of carbid per candlepower-hour is about 4/10 cents for a 24-candlepower burner consuming 1/2 foot of gas hourly.[2]

There are a number of good generators on the market, and the purchaser can make his choice from them. The Davis generator is at present recommended by the Davis-Bournonville Company. This is a lump-carbid feeder made in sizes rangiug from the portable size, charged with 20 pounds of carbid, up to the largest size of 300 pounds' carbid capacity (Fig. 44). Lump carbid, 1 1/4 by 3/8 inches, is charged into the hopper at the top, whence it slides down an inclined plane onto a circular pan. This pan hangs on an axle, which rotates it according to the working of the overhead motor, and the carbid is brushed off the edge of the pan when it rotates. A pressure diaphragm controls the feeding apparatus. The operator sets the diaphragm for a given pressure by moving a weight along the lever controlling the diaphragm. The pressure of the gas can be raised to 15 pounds, is uniform, and is safe-guarded by a blow-off. The water levels are also maintained by overflow pipes. The act of opening the hopper to charge the machine locks the motor, while the position of the motor weight shows at once how much carbid is left in the hopper.

The advantages claimed for this generator are:

[1] Rules of National Board of Fire Underwriters.
[2] Davis Acetylene Company, special information.

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1. That being carbid-fed, the resultant gas is always of a safe temperature, because of the great excess of water it is quenched in.

2. The use of lump carbid ensures slower generation, which takes place after the lumps have gone to the bottom. And lump carbid gives at least 10 per cent. more gas than the pulverized stone.

3. The feed motor is effective: the carbid cannot be overfed and is fed as the gas is needed.

4. The water levels are automatically maintained.

5. All parts are accessible.

6. The charging hopper is perfectly sealed from leakage.

This generator should be installed in a shed outside of the building where the welding is carried on. The shed should be of sufficient size to allow easy access to all parts of the generator, and should be steam-heated with pipes coming from without, so that the water will not freeze up in the winter. No light or fire must be allowed in or near the shed, because of danger from explosions. The shed should be kept locked and closed to all but the regular attendant, who is an experienced hand.

Acetylene gas is much more dangerous than the other illuminating gases, as it will readily explode in mixtures of more or less air than the other gases. Accidents are not so common now as formerly, but happen often enough to show that there is much carelessness in the installation and management of generators, The underwriters' associations of this country and abroad are very rigid in their specifications concerning acetylene generators.

Dissolved Acetylene.—Acetylene dissociates at 780 deg. Cent. into carbon and hydrogen; under pressure of two atmospheres or more, the gas is tricky and is liable to explode. But acetylene is readily soluble in a number of liquids, among them acetone. Acetone is fairly cheap, inert, and incombustible—very essential properties. It boils at 56 deg. Cent., has a strong affinity for acetylene, and is not decomposed by it. At atmospheric pressure and 15 deg. Cent. acetone dissolves 24 times its volume of acetylene. At 12 atmospheres, which is the pressure given the storage cylinders, it dissolves about 300 volumes of the gas and increases in volume 50 per cent. The pressure of such a tank

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is doubled with every rise of 30 deg. Cent., while undissolved acetylene triples its pressure for each rise of 8 deg. Cent.

Berthelot and Vielle[1] experimented with the solution of acetylene in acetone and found that it could not be exploded with an electric spark though under high pressure. Hutton[2] says that, "In practice 1,000 liters of acetylene carry off the vapor of 0.06 liter of liquid acetone"—not an appreciable amount.

All of the above characteristics of the solution recommend acetone as a solvent or body for the storage of acetylene for commerce. The French government was the first to officially recognize acetone storage tanks as safe. The railroads of this country now accept the cylinders for carriage as non-explosive.

Acetone storage was worked out by the Belgian chemists Claude and Hesse, and patented by them in 1897. The principal difficulty to overcome was the factor of expansion of the solution with increased acetylene content, and the corresponding shrinking as the acetylene was drawn out of the tank. The cylinder would be full at 12 atmospheres and only two-thirds full under normal pressure. This meant that a considerable part of the tank would contain the gas alone, subject to the danger of explosion. To overcome this, the cylinder was filled with a porous or absorbent body, which was saturated with the acetone-acetylene solution. Porous brick or stoneware of four-fifths porosity was used; also charcoal cake, bound together with soluble glass; in this country asbestos fiber with soluble glass binder is used. These absorbents will all carry from 50 to 80 per cent. of the solution per volume. When the acetylene is all drawn off, the tank is still perfectly safe and can be recharged simply by passing in acetylene under pressure.

The tanks themselves are pressed-steel cylinders, such as are used for soda-water, and are fitted with cocks and a pressure-regulating valve. They are delivered under 10 atmospheres' pressure, and contain about 100 volumes of the gas—considerably below the saturation content of acetone at that pressure. They should be kept in a cool place, out of the sunlight, because the pressure doubles with 30 deg. rise of temperature. If exposed to too great

[1] *Elec. and Metal. Industry*, March, 1903.
[2] R. S. Hutton, *Elec. and Metal. Industry*, April, 1903.

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heat, the pressure might rise to the danger point, and an explosion take place.

Acetylene storage tanks are of the following size and capacity:

Acetylene Storage Tanks[1]

Diameter in inches	Length, inches	Capacity, cu. ft.	Weight, pounds
7	24	50	50
8	30	80	75
10	30	125	105
12	36	225	120
14	48	400	349
16	48	500	435

Carbid will produce about 4 cubic feet of acetylene per pound; the present price is below four cents a pound. This brings the material cost to about one cent per cubic foot of gas. Stored acetylene costs about twice as much, but its adaptability is much greater and in many cases much more than nullifies the difference. It is claimed to be the purest form of the gas, being practically free from sulphur and phosphorus, because it receives four to six washings.

Practice.—The directions for the use of the oxy-acetylene flame are few and the process is simple, but it takes a skilled workman to get results. Six months' practice is none too long before efficiency can be looked for. It is one thing to melt metals together and quite another to make a weld of homogeneous metal in which strains are at a minimum. The companies print and issue directions, which will be here abstracted and added to. Beyond that it is a question of individual gray matter.

The Flame.—The flame is lighted by first turning on the acetylene, lighting it, and then turning on the oxygen. The acetylene burns with a bright, smoky flame. As the oxygen jet increases, an indefinite-shaped cone appears at the nozzle; it first has two points, one beyond the other. More oxygen reduces it to a clearly de-

[1] Henry Cave, *The Horseless Age*, Dec. 2, 1908.

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fined single cone of blue flame. If there is too much oxygen, the flame will sputter and roar and the point of the cone become ragged and violet-colored. For this reason the operator can always tell by appearance when his flame is right. It is always safer to have too much acetylene, rather than too much oxygen. Oxygen will burn and rust the metal; acetylene will keep it from burning.

The low-pressure flame consumes acetylene and oxygen in the ratio of 1 to 1.50; the high-pressure in ratio of 1 to 1.28.

As to pressure for the gases, the operator will soon learn by trial what pressure of oxygen is necessary to use to keep the flame from back-firing. The low-pressure torch needs higher oxygen pressure to draw in the acetylene; at least 30 pounds for welding and 125 pounds for cutting. Pressure is regulated by turning on the full initial supply of the gases and then setting the constant-pressure regulators. Different kinds of work may take different pressures.

The hottest part of the flame is at the tip of the cone and a fraction beyond. Never hold the cone against the work, because it will burn the metal. Only the tip should be allowed to touch.

HOW TO WELD

To weld, the operator goes over the metal quickly with the flame a number of times. This will heat the metal evenly to about dull red heat. If the work is stock work and is continuous, it will save from 30 to 50 per cent. of time and cost to preheat with a coke, gas, or oil fire or with electricity.

After preheating the seam, the flame is circled about a small radius until the metal softens. Metal is added and worked in with a "melt bar" and care is taken that the edges of the metal are melted and perfectly united. The operator works away from his body and finishes the work as he proceeds. With a little practice the seam can be made quite smooth and even.

Cast iron can be easily welded. It melts easily, is very fluid, and runs toward the heat of the flame. Some care is necessary to avoid its running clear away from the weld. The piece to be welded must be held horizontally or the molten metal must be

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dammed. The melt bar is cast iron and should be low in sulphur and phosphorus and high in silicon. Flux is sometimes recommended, though a skillful use of the flame and stirring with the melt bar will serve the purpose. Salt or borax is a good flux.

Preheating is very necessary in treating cast iron. Heat all of the casting to dull red, or as much as is necessary to prevent cracking. Coke or gas fire is cheapest if there is much welding to be done. Slow cooling is just as necessary as preheating. Annealing may even be necessary to adjust the strains.

Wrought iron requires less care in preheating, though this cannot be neglected. The melt bar is soft iron. Pure iron is sticky and not very fluid. For this reason the softened metal can be stirred into place with the end of the melt bar. It is a good thing to hammer and work wrought-iron joints while cooling so as to build up the structure that the melting has destroyed.

Steel also works well with this flame. The metal becomes soft but does not run. It burns easily in excess of oxygen. Cave[1] states that auto frames can be welded from beneath with the high-pressure torch, because the melted steel adheres well and is spread wherever wanted by the flame. He recommends commercial soft-steel wire for the melt bar. Low-carbon, open-hearth steel is best for the melt bar, because on cooling it is more liable to retain its strength.

Steel welds should also be hammered if possible on cooling, and then annealed. Even then a high-carbon steel will suffer severely within the heating radius. The weld joint can be reinforced, but the heat always extends beyond the reinforcement. In spite of reinforcing, working, and annealing, high carbon and tool-steel joints will lack strength and the elastic limit will be lowered.

Heavy copper articles are seldom welded with this flame, though the results are just as good as by electricity. Because of high heat conductivity a larger flame or more time is needed, and because of the rapid oxidation an excess of acetylene must be maintained in the flame.

Working is very necessary in the case of drawn and rolled

[1] *Iron Age*, Sept., 1909.

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copper, in order to restore the structure; but it would be well for the operator to determine whether the copper is cold-short or hot-short before hammering, otherwise he may fracture the weld.

Brass is a special problem. The hot flame begins to volatilize the zinc of the alloy before the melting point is reached. Hence some covering or reducing flux should be used, such as powdered, fusible silicates, borax, glass, etc. The flux melts and covers the surface. *Bronze* needs similar treatment.

Aluminum is also troublesome because it becomes pasty, and when finally liquid will oxidize rapidly. As soon as the metal at the joint softens it is added to from the melt bar, and the pasty metal is then worked into the seam or patch with an iron spatula. Pasty aluminum can be manipulated like solder. When the joint cools it will be as strong as the body of the piece, if properly worked. If not properly worked, layers of the oxid film will be enclosed in the joint and will weaken it. This film will easily come to the surface with working.

Preheating is very important because aluminum also conducts heat very rapidly. Slow cooling of castings is necessary to prevent tension and cracking. Hammering will give a dense, tough structure, but the operator must beware not to hammer aluminum between 600 deg. Cent. and 655 deg. Cent., the melting point, because it will crumble under the hammer.

Other metals and alloys can be welded, and will be in the future as this process becomes better known. In automobile and machine repair shops a great variety of new alloys are constantly coming up, and the repair man finds that each requires individual treatment, both in handling the flame and in the use of fluxes. As this flame has a possible heat of over 3000 deg. C., it can be toned down to any desired intensity by the use of air in some excess, though at lower temperature it will be increasingly oxidizing.

Similarly, two different metals may be welded, provided their melting points are not more than 500 deg. Cent. apart and provided they will form an alloy. Metals of widely separated melting points will also weld, but the joint may be uncertain. Metals that will not alloy, as iron and zinc, make a poor weld. If one metal is crystalline and the other not, the weld will be poor, as with

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steel and wrought iron. But in contradiction to this general statement, Cobleigh[1] mentions a case where pieces of steel and copper were welded on a piece of cast iron. It looks as though skilled labor will soon be able to weld almost any metals or alloys that will melt.

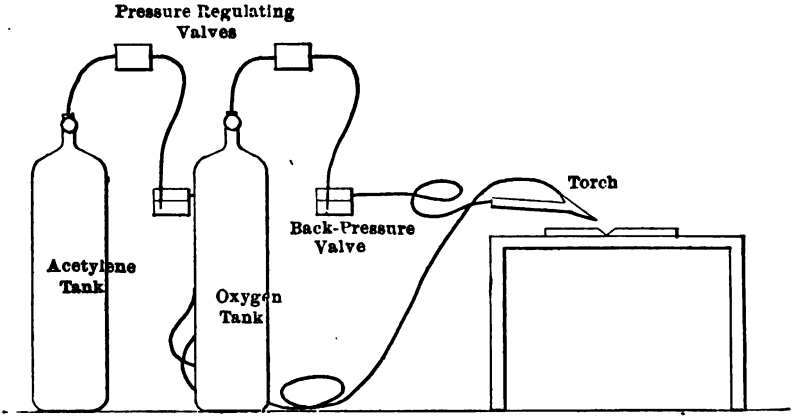

FIG. 45.—Diagram of high pressure oxy-acetylene system, using storage tanks.

There appear to be no limits to the sizes of work this flame can weld. Plates of No. 20 gauge can be butt-welded, while cast iron 14 inches thick has been joined. Large work is commonly chamfered or beveled at about 45 deg. angle to ensure equal melting. When plates are butt-welded, the Linde Air Products Company[2] recommends spreading the far ends of the plates 2 1/2

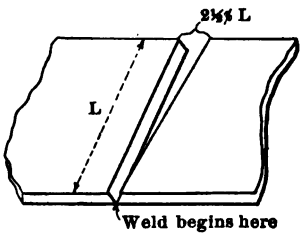

FIG. 46.—Showing adjustment of plates for welding.

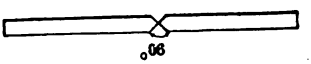

FIG. 47.—Correct bevels for strong weld.

per cent. of their length, as shown in figure 46. This, because the cooling and shrinking of the metal at the weld constantly draws the plates together. The strongest weld can be obtained by beveling both edges and welding both sides of the plate (Fig. 47).

[1] *Iron Age*, Jan. 7, 1909.
[2] Catalog C.

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Although you are sure you have the correct mixture in your flame, examine your work from time to time. If the metal hardens with a spongy or scaly structure, it is burnt and you have too much oxygen.

Always add about one-third thickness of metal to the weld to gain an equal strength. If it is necessary to machine down the joint to unit thickness, you need not count on more than 75 per cent. strength for that joint, though it may run as high as 95 per cent.

As with all melt-welds, the oxy-acetylene weld is benefited by annealing and the elasticity partly restored.

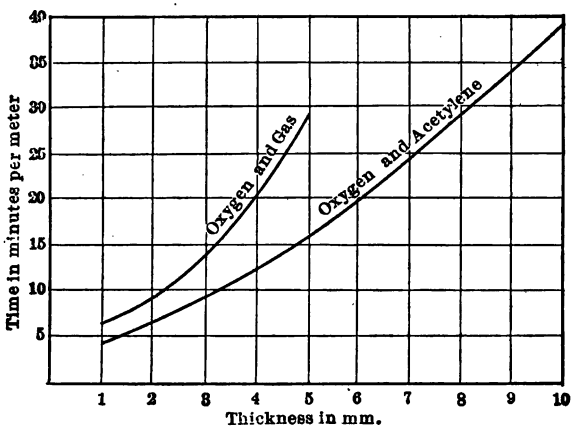

FIG. 48.—Diagram of comparative welding with gas and acetylene (L. L. Bernier).

Adaptability.—As already stated, this process is essentially a repair welding process. We have a very hot flame which we can adjust easily along a large range of sizes. The flame can be turned on or off at will and can be carried into any corner of the work. The flame is practically a hand tool. For this reason the several firms promoting this process are selling easily portable apparatus for use in machine shops, shipyards, automobile repair stations, and manufactories where repair work is daily necessary. The Fore Shipbuilding Company, the Newport News Shipbuilding Company, the Pullman Car Company, National Tube Company, United States Navy Department, and

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many of the big machine shops of the country are using this process for both repair and stock welding.

Chemical and metallurgical laboratories can use the flame to advantage to get very high local heats. It is suggested that the flame may be adapted to assay work where the rock is very refractory. The cost and time needed to get a high heat in an assay furnace is often considerable. With this flame the expensive and fragile muffle might often be dispensed with.

The oxy-acetylene flame is now being used to weld steel tubes for bicycles, automobile frames, steel tanks and cylinders for carbonic acid, etc., angle iron, etc. Quite a bit has been written about the probability of acetylene-welded boilers displacing riveted boilers. Gas-welded boilers have been made, but as yet welded boilers are not recognized as safe, though there is no doubt they can be made so. Figures 50 to 57 show different kinds of repair and job work done by this process.

In the hands of skilled workmen the oxy-acetylene flame is a safe tool for repairing such ticklish work as boiler plates, steel containing-cylinders, steel tubing, etc. But on the other hand, tests of welds have sometimes shown that the metal was either fatally burnt or carbonized. It would be the height of folly to allow a green hand to repair a boiler with this flame. In France an eight months' apprenticeship is required before the workman is allowed to touch repair work. It is doubtful if acetylene welding will replace riveting for boilers or structural iron and steel where the strains are tensional. A good weld is much stronger and also quite a bit cheaper than a single- or even a double-riveted joint. But a riveted joint is of a definite known strength, and a weld may be porous and brittle under a good, smooth surface, and may be less than 25 per cent. strength.

Typical Welds and Repairs.—The following instances of boiler repair are given by L. L. Bernier, in his "Autogenous Welding of Metals":

"Repairing Cracks Steamer 'Eugene Pereire' of the French Line:

"The boiler furnaces of the mail steamer *Eugene Pereire* of the French Line had numerous horizontal cracks above the

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grate bars. There were about 100 of these, and in two of the furnaces they extended from end to end of the corrugations.

"It had been attempted to stop the worst of these by plugging;

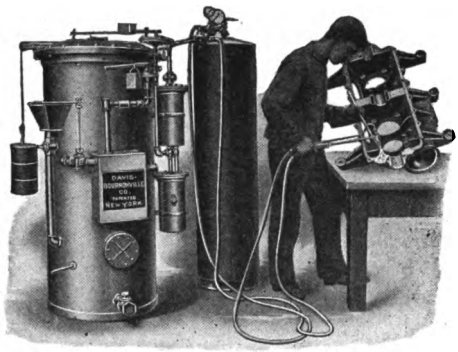

FIG. 49.—Repairing with the oxy-acetylene torch (Davis-Bournonville Company)

but it would have been necessary to renew several furnaces, which would have detained the steamer for two months and caused great expense. All the cracks were wedged open with

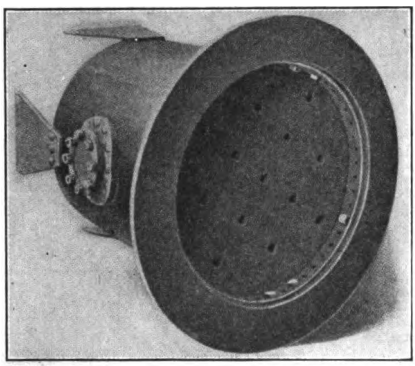

FIG. 50.

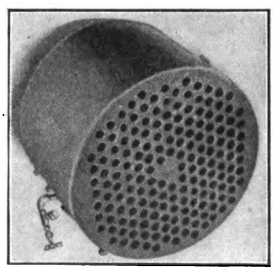

FIG. 51.

FIG. 50.—High-pressure tank for U. S. Navy. Ends and seams welded and 3/4" flange welded to end. Material 1/2 inch thick, size 36 x 30 3/4 inches. Tested to 250 lbs.

FIG. 51.—Steel tubes welded to shell.

chisels and welded; all repaired parts were annealed with burners. In two spots where there were several adjoining cracks, a part of the furnace was cut out and replaced by a welded piece. No

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leak was observed at any of the 100 places so repaired at the hydrostatic or steam tests.

"Only the sweating of a few drops, caused by trifling laminations, were discovered, and a little calking restored the watertightness at such spots. The work lasted three weeks and cost $300. From the month of March of that year the steamer has been on the Algiers voyage, which is very trying for boilers

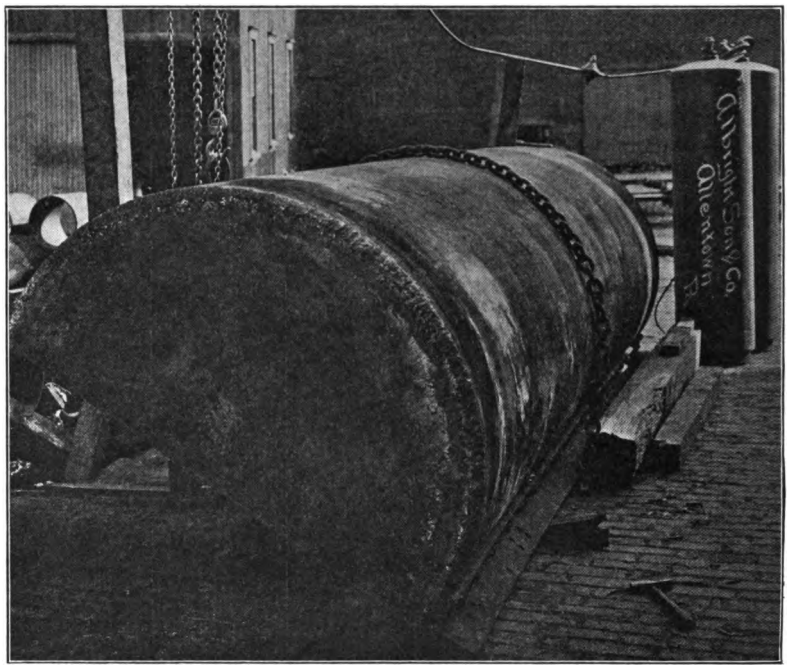

FIG. 52.—Galvanized tank with oxy-acetylene welded end piece (heat expansion would shear rivets).

on account of its shortness, the fires being banked and boiler temperatures changed so frequently. No trouble has been experienced with any of the welded parts."

"Repairing Corroded Parts on the 'Cholon':

"Oxy-acetylene welding may be used to add metal directly to the surfaces of plates, to repair corroded spots, such as are frequently found in various parts of boilers. The flame of the blowpipe is directed upon the plate, and when the latter begins

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to melt the workman presents to the flame a bar of soft steel about 7 by 7, which melts and fixes itself in drops on the corroded surface.

"The repairs of the *Marsa*, already referred to, give a sample of the value of the welding process, but the work performed on the *Cholon*, of the Compagnie des Chargeurs Réunis, from August 20 to September 20, 1906, presents a still more striking case.

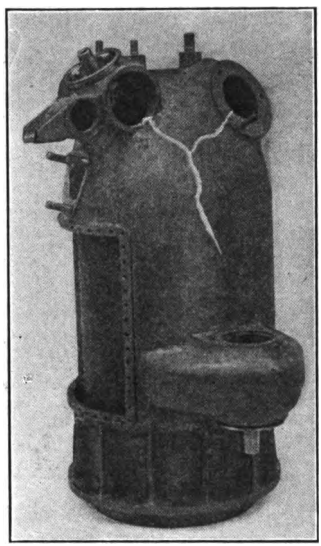

FIG. 53.—Welded cylinder. Oxy-acetylene process.

"The eighteen corrugated furnaces of this steamer were badly eaten away on the surface. There was corrosion on each side and for some distance above the grate bars.

"The work was difficult to perform, as the workmen were compelled to be inside of the boilers; and were inconvenienced by the heat of the blowpipe flame; and the places to be welded were lower than the workmen's footing; 10,000 cubic feet of dissolved acetylene and as much of oxygen were used; about 200 pounds of steel were used to cover the corrosions and restore the plates to their original thickness. This work, at a total

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cost of $2,400, avoided the replacing of eighteen furnaces, as originally ordered by the government inspectors."

Acetylene Welding versus Riveting.—The approximate strength of single-riveted boiler plate is 55 per cent.; of double-riveted, 70 per cent. L. L. Bernier, in the *Boiler Maker*, gives the ratio of cost of acetylene welding with a generator, compared

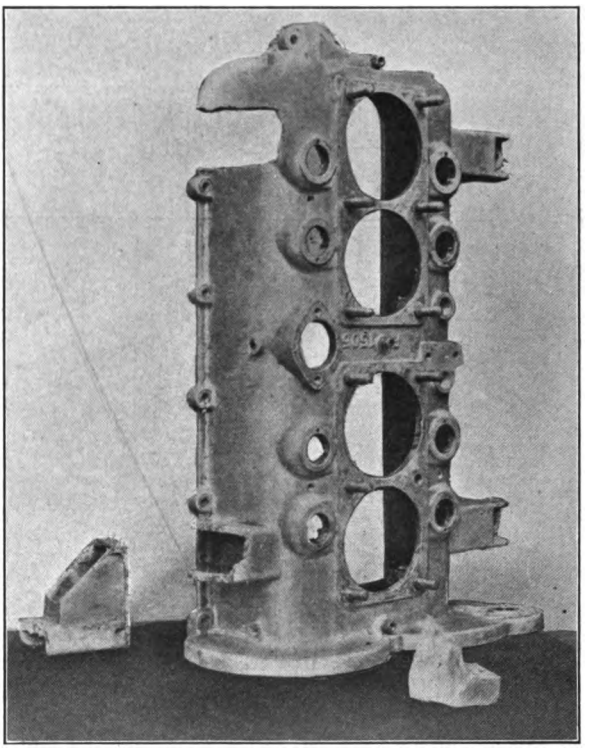

FIG. 54.—Top section of broken crank case with broken arms.

with double riveting, as seven to twelve. The cost of triple riveting is not given, but it would still further increase the discrepancy. Besides being cheaper, the acetylene-weld is absolutely leak proof, a great advantage over a riveted joint.

On the other hand, an apparently sound acetylene-weld may have a tensile strength of 25 per cent. instead of 95, and may be crystalline and brittle; whereas the riveted joint is of certain

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strength. In the present state of the art it would be a mistake to advocate the acetylene-welding of boilers of any size, though for small containers and tubes that can be rolled and annealed the riveted and brazed joint is being rapidly superseded by the acetylene-weld. But oxy-acetylene repair welds are now frequently made on cracked and corroded boilers. Cracks are

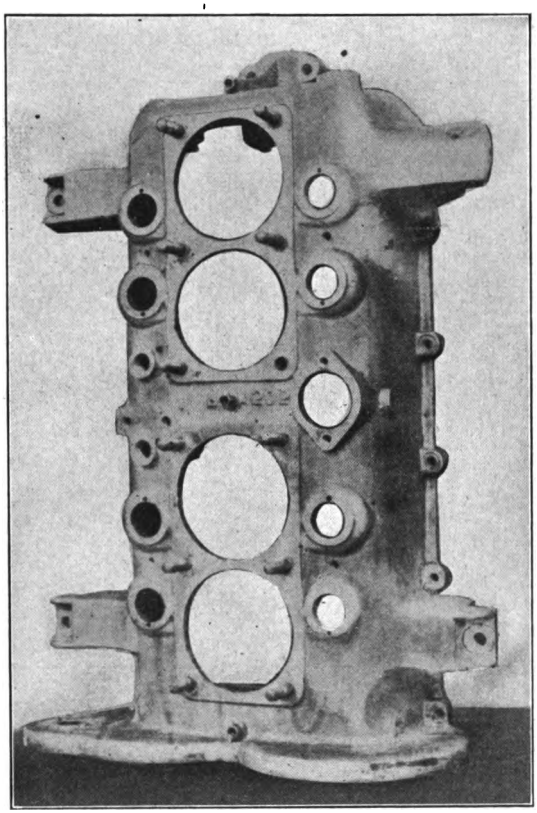

FIG. 55.—Engine crank case with welded arms.

first laid open by a partial heating, until their full extent is known. Then they are welded by the flame and a melt bar, working up from the bottom of the crack. Where the plate is full of cracks or is corroded deeply, a section of the plate is cut out with a cutting flame and a fresh plate patch is welded in. Boiler repairing requires very careful preheating, hammering of

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the weld and subsequent annealing of the plate surrounding the weld.

Repairing Defective Castings.—One of the important possibilities of this process is in the repairing of defective castings fresh from the foundry. Even in the most careful foundry practice the scrap heap is always a very expensive mountain to the foundryman. If he can keep down the heap he can increase his profits. With the oxy-acetylene flame all kinds of defects of

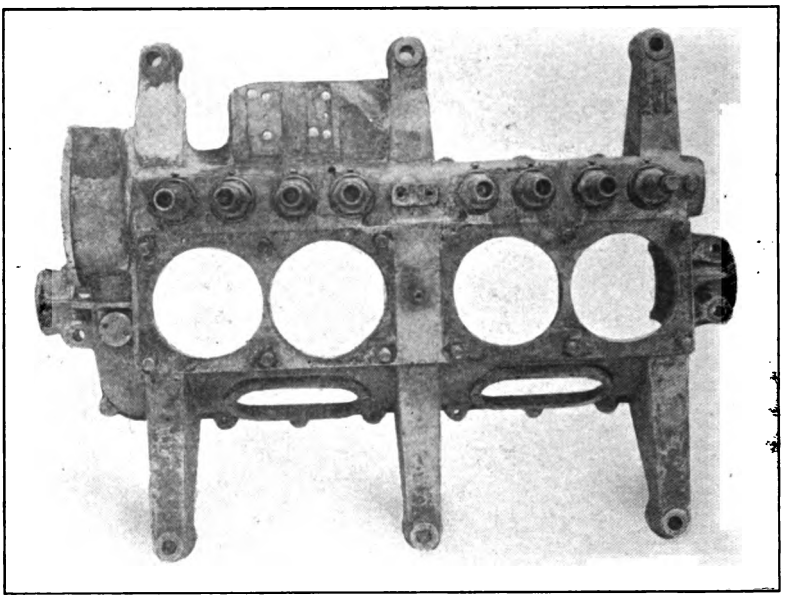

FIG. 56.—Welded aluminum engine bed.

castings can be repaired. Broken pieces can be put together an imperfect pieces built up and repaired. As with other repair work, a preheating torch or furnace would be needed for pieces of any size, even though they were of low-carbon steel. After the acetylene flame had done its work, an annealing furnace would be necessary. Both the oxy-acetylene process and the thermit process (see page 121) offer a solution for the economical reduction of the scrap heap.

But there is one serious limitation to the possibility of using the oxy-acetylene flame or thermit to repair a new casting. Such

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a casting cannot honestly be called new. The repair may make it stronger than a perfect piece, but the fact remains that it is a repaired piece. The foundryman may or may not tell his customer what he is selling him, according to his standard of honesty. It may be difficult to convince that customer that he is getting a first-class article and should pay full price for it. Many customers would not accept it under any sort of guarantee. Again, it might be equally damaging to the foundryman if it became known that he sold as perfect castings which had to be repaired, if he did

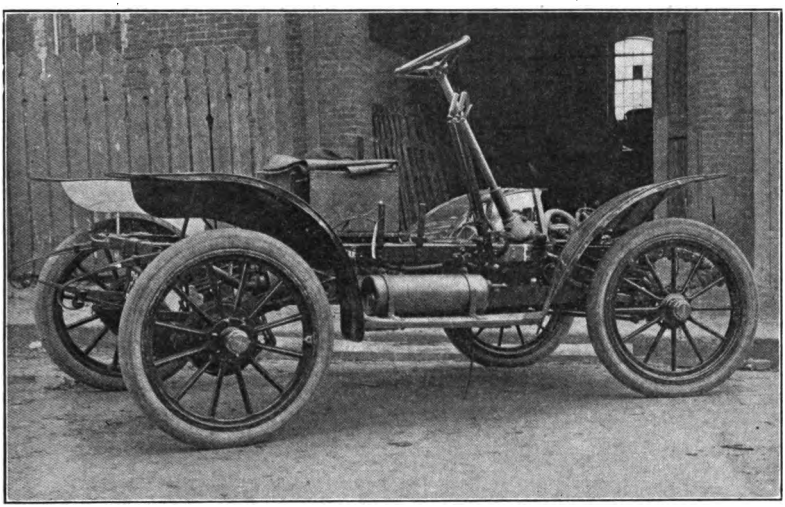

FIG. 57.—Welded auto frame. Weld is at the white line near the base of the steering handle.

so without telling the customer. Again, it is poor practice for the printer, the potter, the foundryman, etc., to accept knock-down prices for a doubtful product, and so admit its inferiority.

The fact remains that this flame offers a fairly cheap way of redeeming defective castings. The founder must use his judgment in employing it.

How to Cut Metals.—Besides its use in melting metals for welding, it has recently been found that the oxy-acetylene flame will cut through metals. The importance of this discovery is not yet realized. Wrought-iron and steel plate can be cut through as fast as a carpenter can tear through scantling with a

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rip-saw; cast iron not so readily. Other metals and alloys, such as aluminum, brass, etc., can also be cut. Jottrand is credited with this discovery.

Cutting is effected by both the melting and the burning of the metal. In the case of iron, the ordinary flame heats it to bright heat, when an extra oxygen cock is turned on. Iron burns with evolution of great heat in the presence of oxygen. At the same time this heat is partly transmitted to the iron in front of the jet, while the jet blows out the iron oxid and molten metal wherever it strikes. When the cutting flame is at its best it entirely oxidizes the iron, blowing out a clean narrow cut. Cutting is a spectacular process, due to the shower of slag sparks that fall from the cut.

While the cutting may be done with the oxygen flame alone, after the iron is red-hot, modern practice uses a preheating torch to which an additional oxygen jet is attached. The torch is the ordinary medium- or low-pressure torch, while the oxygen jet is above 125 pounds. Several firms are selling such torches (see Fig. 36).

The torch is first adjusted to a welding flame, while the cock of the oxygen jet is closed. The operator points the flame at the edge of the metal to be cut. As soon as bright red heat is

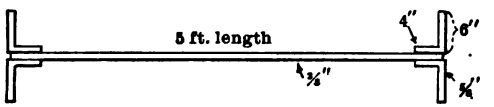

FIG. 58.—Iron girder cut by oxy-acetylene flame.

reached, he moves the flame inward about half an inch and turns on the full oxygen jet which strikes the edge just heated. Meanwhile the flame is heating the new part. For different thicknesses of metal he can use a given oxygen tip, of which each torch has three.

The rate of cutting varies with the thickness of the plate, and the skill of the operator. Roughly, this flame takes from 1/5 to 1/10 the time in cutting a given section of steel that two men working with a metal saw would take. There are several records

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of 4-inch plates cut by it, while the companies claim 6 and 8 inches for it.

An exhibition of flame-cutting was given recently by M. Bournonville. During the extension work for the new New York subway approaches to the Williamsburg Bridge it was found necessary to cut through a 3/8-inch I-beam of steel, whose dimensions appear in figure 58. The entire cutting took 21 1/2 minutes. This gives the reader an idea of the efficiency of this process.

This flame should be used to cut any metal that resists the metal saw. Should it fail to oxidize, it would melt its way through. An oxy-acetylene cutter should be an adjunct to every repair shop of any size. It would be found invaluable in cutting away badly wrenched metal work and in cutting and working on parts of any machine, such as an automobile, where a special fixture was to be fastened. For besides its ability to cut, this flame can be made to pierce rivet holes straight through one-inch steel in less than two minutes.

This flame has found its way into the railroad repair shops, one of which uses it to cut away twisted metal on "gondola" coal cars. These cars are light, strong, and durable, and are rapidly displacing the wooden cars. But loss by wreckage is great and a bad wreck of gondolas is a very difficult thing to handle. The cars are often shapeless masses caught together by the force of the impact, and difficult to separate. It has sometimes been necessary to clear the track with dynamite. Two storage tanks and several burners carried on the wrecking train would be of great assistance in such a wreck.

Every auto repair shop of any size will probably have one of these oxy-acetylene outfits in a few years. The same may be said of ordinary machine shops, car shops, boiler shops, etc.

A table of cutting costs has been worked out by the Davis-Bournonville Company, which is here appended. Oxygen is reckoned at three cents a foot, acetylene at one cent, and labor at thirty cents an hour.

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Approximate Cost of Cutting Steel

Number cutting tip	Use welding tip No.	Thickness of steel	Heating jet. Feet of acetylene	Heating jet. Feet of oxygen	Cutting jet. Feet of oxygen	Pressure of oxygen heating jet	Pressure of oxygen cutting jet	Lineal feet cut per hour	Labor per hour	Total cost per hour	Cost per lineal foot.
1	4	up to ½"	12	15½	60	14 to 18 lbs.	125 lbs.	60	.30	2.68	.0447
2	4	½" to 1½"	12	15½	75	14 to 18 lbs.	125 to 150	50.	.30	3.13	.0627
2	5	1½" up	18	23	95	18 to 22 lbs.	150 to 175	40	.30	4.02	.1005

Costs.—It is, of course, impossible to give costs in an empirical way. In the first place, improved methods of generating the two gases are still being advanced, as well as improved apparatus for production and storage. The prices of raw material fluctuate, and the cost of labor is increasing irregularly. But most serious, no two men are likely to use the same amount of gas nor take the same time for a specific job; nor would one workman be apt to repeat his performance. It at once appears, that outside of catalog prices for apparatus, cost estimating is as difficult as in the printing trade.

I have given cost data at several points which must be taken with a little salt. Before purchasing oxy-acetylene plants, it would always be in order to get estimates and statements from the several firms handling this line; these should advise the kind of outfit for the work at hand.

The table of costs worked out by the Davis-Bournonville Company is appended.

Approximate Cost of Oxy-acetylene Welding

Oxygen at 3 cents, acetylene at 1 cent per cubic foot; labor 30 cents per hour.

Tip number	Thickness of metal	Consumption of acetylene per hour	Consumption of oxygen per hour	Proper pressure in pounds for oxygen	Lineal feet welded per hour	Cost of labor per hour	Total cost per hour	Cost per lineal foot
1	$\frac{1}{32}$ to $\frac{1}{16}$	2.8 feet	3.6 feet	8 to 10 lbs.	50 feet	$0.30	.436	.0087
2	$\frac{1}{16}$ to $\frac{3}{32}$	4.5 "	5.7 "	10 to 12 "	30 "	0.30	.516	.0172
3	$\frac{3}{32}$ to $\frac{1}{8}$	7.5 "	9.7 "	12 to 14 "	25 "	0.30	.666	.0266
4	$\frac{1}{8}$ to $\frac{1}{4}$	11.7 "	15. "	14 to 18 "	16 "	0.30	.867	.054
5	$\frac{1}{4}$ to $\frac{5}{16}$	18. "	23. "	18 to 22 "	10 "	0.30	1.17	.117
6	$\frac{5}{16}$ to $\frac{7}{16}$	25. "	32. "	20 to 25 "	7 "	0.30	1.51	.216
7	$\frac{7}{16}$ to $\frac{1}{2}$	32.5 "	41.5 "	22 to 27 "	5 "	0.30	1.87	.374
8	$\frac{1}{2}$ upward	48.5 "	62. "	24 to 30 "			2.64	

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The following table[1] is intended to show the costs and efficiency of the three principal welding flames. Costs are figured on the basis of generator acetylene one cent a foot; compressed acetylene, two and one-half cents; oxygen, three cents; hydrogen, one cent; coal gas, one and one-quarter cents. I have reduced the estimated temperatures to reasonable limits.

	Oxy-acetylene mixture	Oxy-hydrogen mixture	Oxy-coal gas mixture
Number of B. T. U. obtained by complete combustion of one cubic foot of gas.....	1570	290	616
Temperature (Fahr.) obtained by combustion of the mixture (approx.).....	3000° C.	2000° C.	1700° C.
Cubic feet of oxygen required to burn one cubic foot of gas to obtain the best welding flame (from practical tests made).....	1.30[2] 1.70[3]	0.25	0.67
Cubic feet of oxygen required to obtain 1000 B. T. U. with a welding flame.....	0.765[2] 1.00[3]	0.86	1.09
Cubic feet of heat-producing gas required to obtain 1000 B. T. U. with a welding flame.....	0.59	3.44	1.63
Cost of 1000 B. T. U. (cents)	2.89[2] 3.59[3] (generator acetylene) 3.78[2] 4.39[3] (dissolved acetylene)	5.92	4.20

Chemistry and Thermics.—A definite formula should not be laid down for the oxy-acetylene flame as used. This for the reason that the products of combustion vary with different proportions of the gases and in different parts of the flame. Lewes[4]

[1] *Bulletin Technologique*, Sept., 1907.
[2] Medium-pressure torch used.
[3] Low-pressure torch used.
[4] "Acetylene," Vivian Lewes, 1900, p. 120.

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gives the probable maximum of the flame as lying between 3100 deg. Cent. and 4000 deg. Cent. This forbids the formula of Davy,

$$2C_2H_2+5O_2=2H_2O+4CO_2,$$

because water is dissociated at only 780 deg. Cent. Beltzer makes it

$$C_2H_2+O_2=2CO+H_2,$$

while Beaupré allows less than one part monoxid in 100,000 of the residual gas.[1] Presuming that none of the carbon forms monoxid, Beaupré states that oxids of nitrogen are formed in small quantity and ozone in very appreciable amount. Le Chatelier[2] gives hydrogen, carbon dioxid, and monoxid as the principal gases from burning 7.74–17.37 parts acetylene in 100 parts air. It is quite likely that the layer of hydrogen on the outer surface of the flame is partly burned to water, and partly dissipated.

Theoretically, the acetylene requires about 2.5 parts of oxygen. But practice proves that this gives an oxidizing flame. So the proportion of 1 part acetylene to 1.50 oxygen is recommended. Recently M. Bournonville's experiments have shown that, with his torch in working order and the flame the proper color and shape, the proportion fell as low as 1 of acetylene to 1.28 oxygen.[3] Repeated trials confirmed these figures. However, this seems a small matter. The flame should be decidedly reducing, but should not be so charged with excess acetylene that it will deposit carbon.

The temperature commonly ascribed to the oxy-acetylene flame is 3500 deg. Cent. Acetylene is composed of 92.3 parts carbon and 7.7 hydrogen, according to its symbol. Its temperature of dissociation is 780 deg. Cent., according to Lewes;[4] on burning, its heat value is 310,500 cal., according to Thomsen.[5] This great heat need not all be attributed to the burning of nascent carbon, for the gas is endothermic, requiring 47,700 cal. for its formation.[6]

[1] *Comptes rendu.*, 1906, 142, 165–6.
[2] *Comptes rendu.*, 121, 1144.
[3] Special information.
[4] "Acetylene," Vivian Lewes, 1900.
[5] *Thermochem. Unters.*, 4, 74.
[6] Roscoe and Schorlemmer, Vol. I, p. 770. "Treatise on Chemistry."

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Le Chatelier[1] gives formulas of reaction and temperatures for three different mixtures of acetylene with air, and shows that a minimum of air produces carbon dioxid and water; and an excess of air, carbon monoxid and hydrogen. In any case, the flame if properly handled is reducing beyond the blue cone, which should never be allowed to more than touch the work in hand. Such hydrogen as remains unburned in the flame is claimed to form a protecting envelope.

Testing.—It is natural to expect that a unit cross-section of an oxy-acetylene welding will not be of equal strength with the metal before welding. The metal has been melted, perhaps oxidized or carbonized slightly, and has cooled quickly. If the weld is not pounded or worked while cooling, the chances are that the metal has crystallized and is brittle. The average oxy-acetylene weld is more brittle than the metal itself, and has from 60 to 95 per cent. of the tensile strength. To make a weld as strong as the unwelded metal, an upset or extra thickness of metal must be added to the weld. Some writers make the ridiculous statement that the weld is even stronger than the original metal. This is only possible when a large joint is made. And in any event the elasticity is much reduced even when the joint has been hammered or pressed.

But for its purpose, when carefully made, the acetylene weld is strong enough and compares favorably with welds made by other processes. Tubing, automobile frames, boiler patches, and miscellaneous joints which have successfully withstood the excessive shocks, stresses, or pressures demanded of them, all attest to the ability of the acetylene welder to do good work.

THE OXY-HYDROGEN PROCESS

General.—The oxy-hydrogen flame is the first, historically, of the high-temperature flames. It was used long before the discovery of industrial electrolysis of water or the production of oxygen by liquid-air process. The first flames were fed with *oxygen* generated from potassium chlorate and manganese dioxid or from the decomposition of sodium and potassium peroxids

[1] *Comptes rendu*, 121, 1144.

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with water or similar methods, and with *hydrogen* from zinc and hydrochloric acid or similar methods. Both the hydrogen and the oxygen can be used independently for the following combinations, the hottest first:

1. Oxy-hydrogen.
2. Oxygen-coal gas.
3. Air-hydrogen.

Apparatus.—The first efficient apparatus was devised by Newman,[1] who used pure oxy-hydrogen (detonating gas) under 2 or 3 atmospheres' pressure. The burner was a glass tube about 4 inches long, of 1/80-inch bore. The flame was kept at the tip by reason of the pressure and the narrow bore. In 1847, Robert Hare, of Philadelphia, fused 2 pounds of platinum with a blowpipe of his own invention. He also used detonating gas; and as a safety device, to prevent back-fire explosion, a handle packed tight with copper rods, through which the gas was forced to the tip. This acted on the principle of the Davy lamp. In 1859 Deville and Debray revived this flame for platinum welding, and since then it has been employed in working that metal and also, sometimes, for gold and silver.

At the present time the oxy-hydrogen flame is much used in laboratories for production of high heat and to a limited extent in repair and boiler shops. It has long been the preferred method for sealing lead chambers for sulphuric acid manufacture by the contact process. Before the advent of the electric arc, bright light was obtained by heating a chunk of lime in this flame. This once widely advertised light is almost unknown at present. Before industrial oxygen and hydrogen were made by electrolysis of water, this flame was quite expensive, and recently it has been crowded severely by the oxy-acetylene process. But in platinum welding, lead soldering, and laboratory research it holds its own.

Detonating gas is made by the decomposition of water without separating the resultant gases. It can be used for soldering and welding, provided the burner is protected from back-fire, by passing the gas through a safety chamber filled with fine porous material or guarded by a water valve. Detonating gas is comparatively cheap, though the railroads often object to handling it.

[1] Encyclopedia Britannica, Vol. XVIII, p. 105.

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Separate oxygen and hydrogen are to be preferred on account of safety.

The outfit consists of tanks of the gases, tubes, and a burner (see Fig. 59). To prevent one gas from flowing into the other gas supply tank, if the pressure of the second gas should fail, each leading tube is provided with a safety water valve. The burner is a tube in a tube: the inner tube carrying oxygen, the

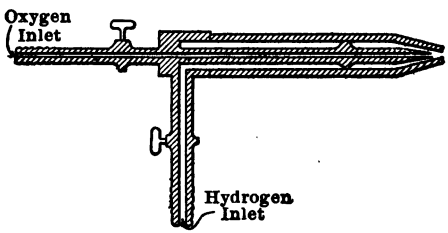

FIG. 59.—Oxy-hydrogen blowpipe.

surrounding tube hydrogen. Both have cocks. The hydrogen is first turned on and lighted; then turn on the oxygen. This burner is also suited for oxygen-coal gas.

Figure 60 shows the air-hydrogen torch; the hydrogen is injected at the handle and draws in air through holes in the tip. The amount of air is regulated by a ring. This burner resembles the Bunsen burner, and is used for small work, where great heat

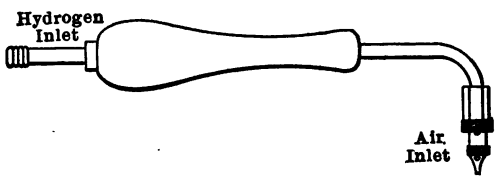

FIG. 60.—Hydrogen-air blowpipe.

is not needed. The hydrogen may be produced by the zinc-acid process.

M. U. Schoop,[1] the welding expert, recommends the burner shown in figure 61 for large-scale work. The torch has two chambers. The first is filled with oxygen. The hydrogen tube passes through this chamber into the second. The injected

[1] *Electrochemical and Metallurgical Industry*, July, 1905.

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hydrogen draws oxygen from the first chamber into the second, where they mix before coming out at the nozzle. This torch is liable to back-fire, but it gives a perfect combustion and prevents free oxygen in the flame.

The air-hydrogen process is apparently cheaper, but when it is considered that much less heat is evolved and that three hours' time are needed to one hour for oxy-hydrogen, it turns out to be dearer. Schoop claims that it is more dangerous than oxy-hydrogen. It is the preferred flame for "lead burning," as the sealing of lead seams is called. C. H. Fay[1] has explained the

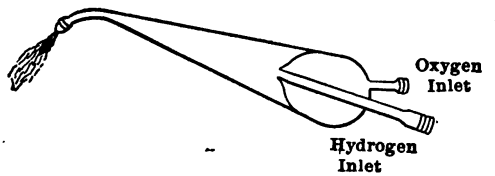

FIG. 61.—Oxy-hydrogen burner allowing perfect mixing of the gases.

apparatus and process in great detail. He used apparatus of the Kirkwood & Herr Hydrogen Machine Company, of Chicago. It included: an air gasometer; a hydrogen-generating apparatus, using zinc and sulphuric acid; and a regular burner with two cocks. If the hydrogen was used under pressure up to 30 pounds, the air gasometer could be done away with, and air introduced by injection instead.

The Flame.—Oxygen and hydrogen for combustion are mixed in a long-shanked burner at the lower end of the handle. They burn at the tip with a pale blue, almost colorless flame. The theoretical formula of combustion is

$$2H_2 + O_2 = 2H_2O.$$

Though these gases will unite as low as 155 deg. Cent.,[2] the action is slow. Explosive ignition of mixtures of the gases in different proportions occurs at an average temperature of 825 deg. Cent. Richards[3] gives the temperature of the hottest part of the flame as 3191 deg. Cent., and of the air-hydrogen flame as

[1] "Lead Burning," 1905.
[2] *Electrochemical and Metallurgical Industry*, May, 1905.
[3] Roscoe and Schorlemmer, Vol. I, p. 287, "Treatise on Chemistry."

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2010[1] deg. Cent. Bunsen's experiments gave a maximum of 2844 deg. Cent. The former temperature, of course, is not to be found throughout the flame, if at all. The actual temperature is probably not much above 2000 deg. Cent. under working conditions, and while this is above the fusion point of most of the metals, it is none too high when conduction is reckoned on. The heating value of the hydrogen flame is much less than the acetylene, being 67,940 calories.

Practice.—In using the oxy-hydrogen flame it is necessary to use an excess of hydrogen over the theoretical amount of two volumes to one of oxygen. Otherwise there is danger of oxidizing the metal surface with hot oxygen. Platinum is the exception. This metal absorbs hydrogen and swells up. When cooling, it occludes the gas and becomes rough and pocked. One writer[1] recommends 4 to 5 volumes of hydrogen to 1 of oxygen for ordinary welding. This is so in the case of iron, copper, aluminium, and other oxidizable metals, when the unmixed-gas type of burner is used. But no such excess is necessary where the gases are mixed before ignition.

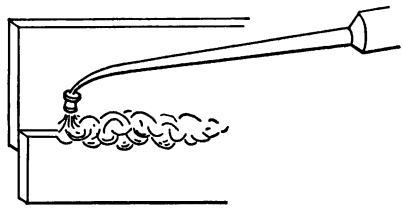

FIG. 62.—Lap welding lead sheets with air-hydrogen flame.

In lighting the oxy-hydrogen burner, turn on two-thirds of the hydrogen first and light it, then turn on oxygen until you have a pale blue conical flame. Then turn the hydrogen on full. If the burner is of the type shown in figure 61, do not light for at least ten seconds; and turn the oxygen off first when extinguishing.

The air-hydrogen flame, being cooler, must be larger. Hydrogen is turned on and lighted first. The flame will be about 3 inches long, pale red, and will burn unsteadily. Now turn on air until the flame shortens to 2 inches and has a fixed, pale blue cone. If you are using an injector air-burner, you regulate the air by turning the air ring.

In using either flame do not bring the end of the cone of

[1] *Electrochemical and Metallurgical Industry*, May, 1909.

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oxygen against the work in hand. If you do, you are liable to burn your metal.

The operator is advised to use a flame of such size that it will not melt the metal at once. Slow melting will make a better job, and the metal will not be so apt to run away from the joint before he is prepared for it. Operators commonly weld a drop at a time as shown in figure 62. They then go back over the seam a second time to smooth off the surface.

Different metals require different treatment. There are little points in the handling of this flame that the operator will have to work out for himself. Like any highly efficient tool, it requires a skilled workman.

"The time[1] for welding 1 meter of sheet iron 3 mm. in thickness is about 15 minutes, while for welding 1 meter of sheet metal of 0.5 mm. thickness, it is from 4 to 6 minutes."

[1] *Electrochemical and Metallurgical Industry*, F. C. Perkins, May, 1906.

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PART IV—THERMIT

THE THERMIT PROCESS

General.—One of the most recent and successful methods of welding is called the Thermit Process. It was invented by Dr. Goldschmidt, of Essen, Germany, and is exploited by the company bearing his name. In this process a mixture of aluminum and oxid of iron is ignited. The aluminum reduces the iron from its oxid, and evolves an intense heat, about 2500 deg. Cent., or twice the temperature of molten steel. This molten steel, called thermit steel, is then poured around the metal to be welded and forms a melt-joint that is very strong when cold. Its present application is entirely in repairs of large metal pieces and in making continuous welded railroad track. It is used in repair shops for mending car axles, auto and electric motor cases, broken and defective castings, broken parts of reciprocating engines, broken rudder-posts, skegs, and sternposts of ships, and for repair work in general along this line. Special thermit mixtures are being advocated for toning up the melted steel in the ladle in foundry practice, for preventing "piping" of ingots; and the company is using the strong reducing property of aluminum in reducing a number of the less used metals, such as tungsten, chromium, and boron, to a pure metallic state.

Thermit is first of all a welding process. Its good and weak points may be summed up thus:

1. Simplicity of the apparatus.
2. No special skill needed to do the work.
3. Possibility of repairing breaks difficult of access and of repairing parts *in situ* that would otherwise have to be taken out.
4. Possiblity of intense local heating of large parts.
5. Time and money saved in most repair work.
6. Possibility of varying the chemical composition of thermit steel so that its properties may be varied.

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7. It is at present limited to rail welding and repair work.

8. Only iron and steel can be welded.

9. The cost, though much lower than the forge method of welding, is still often prohibitive.

The process is used by many of the leading railroads, shipyards, and machine shops of all of these countries, both for repair work and for special jointing, such as that of the third rail of the Paris subway. At present Dr. Goldschmidt is trying to produce chemically pure metals on a commercial scale. He has met with success in reducing metallic manganese, chromium, tungsten, vanadium, molybdinum, boron, etc., from their ores and oxids. This new field in metallurgy, now called aluminothermics, seems to promise as many new and interesting possibilities on its horizon as did the experiments of Moissan with his electric furnace.

The fundamental idea beneath thermit has been in the minds of metallurgists for at least a half-century. In the year 1869, a Mr. Budd[1] describes a process for reducing the alloyed silicon in pig iron. His idea was to burn it out with hematite ore, the formula being:

$$3Si + 2Fe_2O_3 = 4Fe + 3SiO_2.$$

He made a paste of hematite and smeared it over the bottoms of the pig molds. The molten iron, which appears to have been much too high in silicon, was run into the molds, and immediately the silicon began to burn out of the iron, first taking up the oxygen of the hematite mud on the bottom of the mold, and then uniting with some of the iron and coming to the top as a silicate-of-iron slag. Most of the iron reduced from the hematite added itself to the pig. Like the Goldschmidt method, this was the reduction of one metal by the transfer of its oxygen to another metal.

The fact that aluminum has the greatest affinity for oxygen has long suggested it as a final reducing agent. And its steady fall in price since its discovery by Woehler in 1857 finally brought it, about 1895, within range of the market. Woehler himself tried to smelt chromium from its chlorid by ignition with metallic

[1] *Transactions of the Iron and Steel Institute*, 1869; "On a New Process for Removing Silicon from Pig Iron."

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aluminum. After an explosively violent reaction, he found he had an alloy of chromium with aluminum.

A number of later attempts were made to use aluminum as an agent for reducing the rare metals from their oxids. Yet, though it had an intense affinity for oxygen, the combustion was hard to start, and when started was hard to control. Experimenters mixed it as a powder with a metallic oxid and heated the mixture from the outside. Finely divided metallic aluminum will not burn at the temperature of molten cast iron. So that when the contents of the crucible began to react, the initial temperature was already so high that the reaction was an explosion. Dr. Goldschmidt overcame this by setting off the cold powder with a fuse of barium peroxid, BaO, which in turn was set off by a storm match. A charge of several pounds was found to burn in less than 30 seconds, and the temperature of the mass rose to an approximate 2500 deg. Cent. Larger quantities, though starting to burn from a cold and coarsely powdered sand, often boiled over. A premixture of cold steel turnings remedied this. The result of the burning was an intensely hot iron whose composition could be varied at will.

The commercial value of this invention is obvious. There are many processes and many emergencies where a very hot molten iron is invaluable, yet where it is difficult and expensive to get this heat by any known means. Take the case of a broken casting of some large machine that would in the ordinary course of repair have to be taken apart and shipped to the nearest forge to be welded. If, however, a definite quantity of iron, heated to twice its melting point, can be made on the spot, it can be poured around this break without dismantling the machine. It will then form a welded union, much as though one were to put the butts of two candles together and pour hot tallow over the joint. The tallow would melt into the candles before it itself cooled, and join the two with a homogeneous substance.

In order that the mechanical aspect of the thermit weld may be clear to the reader, a simple case of rail welding will be outlined. After which the appliances used in the process will be described in detail.

Apparatus and Rail Welding.—Suppose a case of two rails

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abutting which are to be welded together. It is a railway crossing where heavy trains pound. The weld must be at least as strong as the rail. It must be so made as not to interfere with the travel of the wheels by coming up over the head of the rail. First of all, the rail ends must be cleaned of oxid and grease with a sand blast or emery-paper or hydrochloric acid. Next, the rail ends are heated to a dull red heat with a kerosene or, preferably, a gasoline torch. This merely assists the hot thermit metal and prevents a premature chilling of the thermit when it is poured in the mold. Two clay molds are next clamped on either side of the junction. The shape of the interior of these molds is, of course, determined by the shape of the collar which is intended to be cast. In this

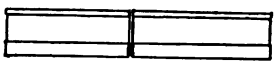

FIG. 63.—Rails before welding.

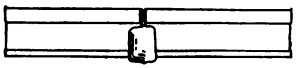

FIG. 64.—Welded rail, showing thermit-steel shoulder.

case, as shown in figure 64, the collar should extend 2 inches over each rail end. It shall be twice as thick as the shank of the rail and also the base of the rail. It shall stop short of the rail heads, which shall remain free. The mold is constructed so as to allow the molten metal to be introduced from the bottom, as shown in the figure. After coming in from the *runner*, at the bottom, the slag and excess steel overflow into the *riser*.

We have then two rails enclosed in a mold whose capacity, over the rails themselves, is known. To produce enough thermit steel to well fill this mold and to allow as much more to fill the *runner* and the *riser*, *take eighteen times as many ounces of thermit powder as there are cubic inches of surplus space in the mold.*

The above amount is arrived at as follows: One cubic inch of steel weighs 4 1/2 ounces. Four and one-half ounces steel is produced by twice as much thermit powder by weight, or nine times. And as the runner and riser take as much fluid as the inside of the mold, we multiply again by 2 and get *eighteen.*

When a *wax collar* is first built on the joint, the amount of thermit should be *thirty-two times* the weight of the wax used. The weight of the wax used is found by subtracting the weight of

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the piece of wax remaining from the total weight of the original wax lump.

The proper amount of thermit powder is poured into the cone crucible (Fig. 65), and a spoonful of barium hydroxid is heaped upon the thermit. The crucible is placed with its tap hole about 4 inches above and directly over the hole of the riser in the mold. Set off the barium powder with a storm match and get away as soon as the barium is caught. The burning quickly spreads from the barium fuse to the thermit, and in a fraction of a minute the entire contents of the crucible are boiling at a temperature of about 2500 deg. Cent. White smoke, flames, and drops of white hot slag are ejected during the combustion, which is most spectacular and reminds one of the blowing of a Bessemer converter. In working with thermit is is well to wear smoked glasses, as the glare of the reaction and the hot fluid is troublesome. In about thirty seconds the reaction is completed, but the crucible should be allowed to stand for a half-minute longer to enable the slag to rise to the surface. It is probably for the reason that the slag does not have time to rise before the workman taps his crucible that the joints sometimes show blow holes and faulty structure. About a minute after lighting the fuse, the workman knocks the stopper out of the bottom of the crucible, and the white-hot metal pours out into the mould. As the stream enters the mold from below (Fig. 71) it heats the ends of the rails and passes on up and out into the riser. The last of the metal stream remains in the mold, and as it is very much hotter than the melting point of steel, it eats into the sides of the rails and knits fast on cooling. The joint should remain undisturbed for at least five minutes to allow the metal to harden. It may then be treated in a number of ways—either allowed to cool slowly in the mold, in which case the joint will be composed of soft, tough steel, or quenched in oil from a red heat, in which case the joint will be very hard, and perhaps brittle.

While this description does not give all of the steps of rail welding, it will give the reader a fair idea of how all thermit welds are made. The apparatus used is as follows:

The Crucible.—With the exception of butt-welding, where an ordinary hot crucible is used, the crucible for all thermit-welding

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is a cone-shaped affair that taps at the bottom. It is an evolution of the thermit process, and is so designed that the molten iron can be drawn off before the slag (Fig. 65).

It is in the shape of an inverted cone, having a rounded iron top which is clapped on as soon as the charge is fired to prevent spattering and loss of heat. The crucible is tapped through a hole in the bottom. It is supported on a tripod or can be slung from a crane or overhead arm.

The body is of pressed steel, lined with several inches of magnesia. Magnesia is slightly more refractory than silica and it has the advantage that it will not unite so readily with the molten steel. Hence the steel remains basic.

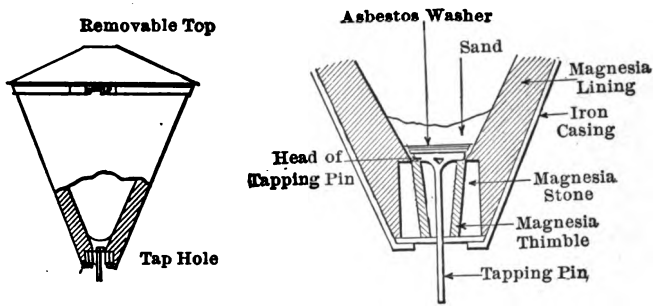

FIG. 65.—Thermit crucible with detail of lap hole.

The tap hole is the vital part of the crucible. It must remain fluid-tight until tapped, and must then withstand the rush of molten steel under pressure. As shown in figure 65, the bottom of the crucible holds a large cylindrical magnesia stone which has been placed in position before the magnesia lining has been tamped in. Resting inside the stone is another conical-shaped magnesia stone, called the "thimble." It is also hollow, and its core is the channel for the molten steel. An iron tapping pin, having a long shank and a flat head, is dropped into the hole in the thimble; its head acts as a plug to the channel. An asbestos washer is dropped on the head of the tapping pin, then an iron washer, and next an inch of silica sand is poured on the iron washer. This makes a plug to the crucible that is fluid-tight for at least a minute, long enough for the reaction to take place.

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This plug is tapped by driving the pin up from the outside by hitting it with a spade. The fluid rushes out and melts the tapping pin as it goes.

A new tapping pin is needed with each reaction; a new thimble

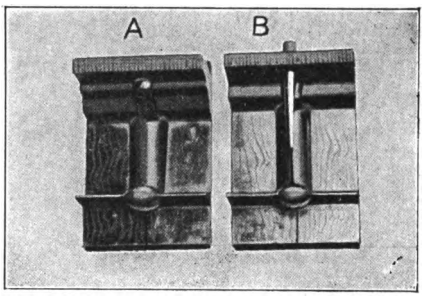

FIG. 66.—Rail patterns.

every eight or ten reactions; a new crucible lining every twenty to more reactions.

The lining of the crucible is a mixture of tar and magnesia, which is tamped in between the crucible steel and an iron matrix. When lined, the crucible is baked at a red heat for six hours, when the lining becomes hard. Even such a substance as mag-

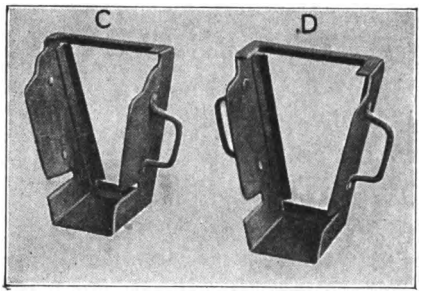

FIG. 67.—Rail mold boxes.

nesia melts away under the heat of the thermit reaction, and after several melts the interior resembles the walls of a Bessemer crucible.

The Mold.—Molds for thermit work are adapted to the particular joint to be made. For welding a number of joints of uni-

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form size the company furnishes patterns with which the operator can make his own molds, or else the company will furnish the molds themselves. Thus it will be convenient and cheap to buy or make special molds for continuous rail welding, pipe welding, rod welding (as in the case of steel rods in reinforced concrete), locomotive-frame welding, or in other repair work that turns up regularly.

Take the case of rail welding, such as the welding together of a continuous third rail for the Paris, France, subway. We will presume the mold patterns (Fig. 66) to represent the obverse shape of the rail. The patterns are laid down, face upward,

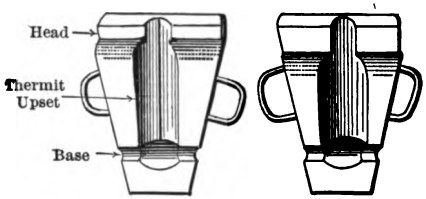

FIG. 68.—Finished rail molds.

and covered with their respective mold boxes (Fig. 67). The molding material is then rammed into place, and when the box is level-full, the operator pricks a number of holes all the way through the mold to allow the escape of gases when the mold is in use. As soon as formed the molds are placed in a drying oven for six hours at a heat of 500 deg. Fahr., until they have become a light brown color. Do not let them burn black, as they will then crumble easily. The molds are generally cast inside of an iron retaining frame or with iron handles.

Mold sand must be more refractory than the ordinary river sand, which has enough iron and alumina in its make-up to render it easily fusible by the hot thermit. Coarse white silica sand and fire clay in equal proportions is the best, price considered. Cheap rye or wheat flour, proportion of 1 to 15, is the binder used. The sand and flour are mixed dry and then moistened to a stiff mass. Where an extra strong mold is needed, the

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operator can mix a spoonful of turpentine to each mold portion. For binding material it is not advisable to use the foundryman's occasional expedients, such as molasses, larger amounts of flour, clay, pitch, etc., for two reasons: The binder is subject to the great heat of the molten thermit. The more binder used, the greater space will be left when it burns out, and the mold will

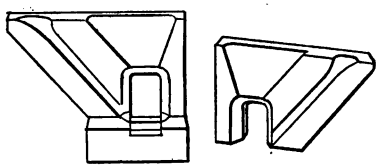

FIG. 69.—Mold partially assembled.

fall to pieces after two or three usings. Also, if much binder is used, its rapid burning will cause excessive gases which may burst the mold, and which are also liable to injure the composition of the steel joint.

A good sand-flour mold should last for ten or more welds. Its life depends on the operator's skill in making and his care in using it.

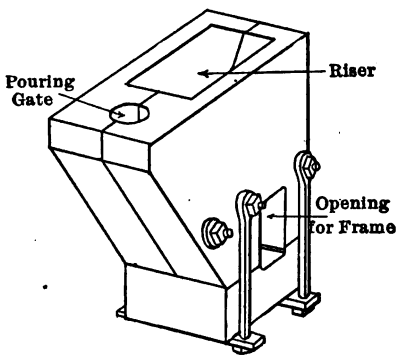

FIG. 70.—Assembled thermit mold.

For the welding of *joints similar to rails*, the molds used will vary in shape, but have the same composition. The operator can carve his own patterns out of wood.

For *butt-welding* of pipes not exceeding a diameter of 1 1/2 inches and of solid rods not exceeding 4 square inches cross-

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section, an *iron mold* is preferable because it is solid and easy to handle (see Fig. 75).

For *welding* larger breaks, such as fractured *locomotive frames*, the fire-clay, or fire-brick, mold is recommended. In this case the cross-section to be welded may range from 2 by 3 to 5 by 6

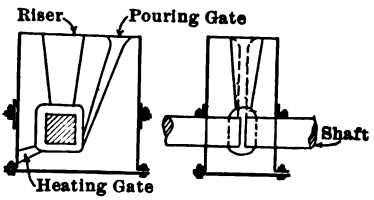

FIG. 71.—Sectional view of mold.

inches. An iron mold would absorb the heat too rapidly. The thermit collar would chill prematurely, and the mold itself would probably crack or melt, being cast iron. While a soft sand mold would propably crumble. The company furnishes a hard-baked, fire-brick mold, which is strong and refractory, at the same time being a fair non-conductor (Figs. 69 and 70).

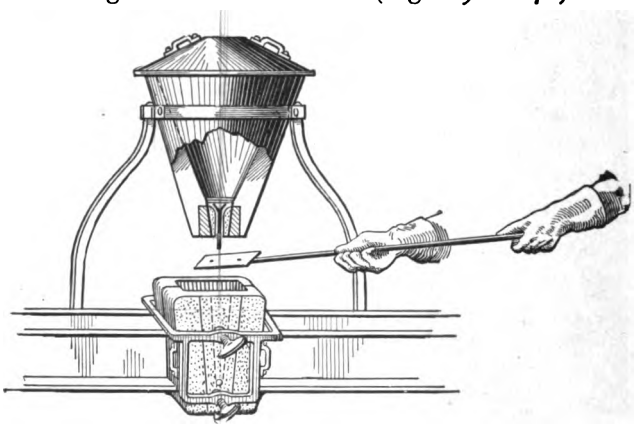

FIG. 72.—Tapping the crucible.

It often happens, in thermit repair work, that the fracture to be mended is of a peculiar shape. The operator will be at a disadvantage in making his patterns, as the fracture is not only irregular, but the shape of the piece prevents measurements for a mold being taken. In this case the operator builds up a collar

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of cerecine wax of the size and shape that he intends for the finished welded collar. He then places the piece in an iron mold box, and tamps it around with wet sand, at the same time inserting wooden forms for pouring gate and riser; he next turns the flame of a gasoline torch into a special hole in the bottom of the sand box. The wax melts from around the piece and runs out of the hole. The flame is continued until the sand is dried, and then the operator stops the bottom hole in the mold with a sand plug. As already suggested the amount of thermit powder necessary for such a mold is *thirty-two* times the amount of wax, by weight. It should take less than twenty minutes to place a wax collar on an ordinary break and twenty minutes to dry out the mold. The cost of the wax is about ten cents per pound, so that for mending occasional or oddly-shaped breaks the wax mold is the cheapest and quickest. It is used for welds of embossing- and stamping-press pieces, forging hammers, stern-posts and rudder-posts of sailing vessels, gun-carriages, motor cases, etc., etc.

Practice.—It should be borne in mind that the thermit joint itself is a steel casting of average analysis of:

Carbon	0.05 to 0.10
Manganese	.08 to .10
Silicon	.09 to .20
Sulphur	.03 to .04
Phosphorus	.04 to .05
Aluminium	.07 to .18

Its average tensile strength is about 30 tons per square inch cross-section. If the joint is good, the thermit will amalgamate so closely with the metal of the welded parts that a ground and polished section of the joint will not show any marks of junction, even though the metals be of different color and structure. Therefore, the operator has only to calculate whether he shall vary the chemical composition of his thermit to give his weld the desired strength or whether he should gain strength by casting a big shoulder on the joint.

There are a number of instances where the shoulder must be machined off, though the weld must be as strong as the rest of the piece, as in the case of rails, bearings, etc.

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Most welds permit of as large a shoulder as is needed, as in the case of ship stern-posts.

To make sure that the metal of the shoulder adheres to the parts, the latter should be made hot before the thermit is poured. If the shoulder is simply a loose collar of metal around the part, it does not add to the strength of the weld. Where the welded part is subject to bending stresses, it is important that the shoulder be knit to the surface of the parts welded. The company recommends heating the parts to redness if possible before pouring the thermit.

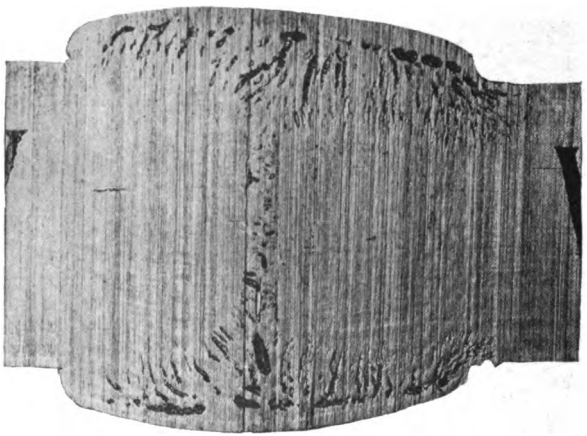

FIG. 73.—Reproduction of photograph of a weld showing "blow" holes.

It is claimed that the air holes and shrinkage cavities, which thermit steel sometimes shows, are also due to insufficient heating (see Fig. 73). Where the parts to be welded are quite cold, it is probable that the thermit steel freezes as soon as it touches, causing imperfect circulation around the joint, and hence allowing a faulty structure in the weld.

Blow holes and separation planes are two of the common diseases of the thermit weld. Faulty mixing of the thermit "tonics," improper preheating, and improper pouring or tapping are all blamed for these defects.

Setting the Pieces.—Where two pieces of iron of more than 1-inch section are to be joined, it is best to allow a 1/2 inch space between the abutting ends, for it is necessary that the thermit

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have free flow around the ends. It must either melt the abutting ends or there must be a passage between them for the thermit to flow.

In the case of rails, the ends of the rails are brought close together, as the thermit can easily melt the ends. The same is also true in the case of small rods and pipe. It is important to keep the rails in perfect alignment while welding.

In the case of locomotive frames where it is doubtful whether the thermit could melt its way into the fracture, the operator drills a line of 1/2-inch holes down the break; through these holes the thermit enters (see Fig. 85). Also in the case of anchor flukes, ship's stern- and rudder-posts, large castings, such as anvils, hydraulic hammers and presses, etc.

In the case of locomotive frames and driving-wheel spokes the shrinkage of the joint on cooling will spoil the piece if not allowed for. The locomotive frame is jacked open from 1/8 to 1/16 inch before the mold is placed. In the case of the driving-rod equal expansion of the other spokes on the piece can be had by heating short sections of each spoke to redness until the weld around the broken spoke begins to set. All the spokes will contract together and the strain will be minimized.

Cleaning the Pieces.—The thermit reaction consists in the reducing of iron oxid by aluminum. Hence it is supposed that the thermit steel, when molten, will clean the scale off the joint to be welded. So it will; but this scale will go into solution as iron oxid. If there is much scale on the joint, the thermit joint will become full of iron oxid and will be "burnt" and brittle. Contrary to the advise contained in the company's directions, I would recommend that the pieces be kept as clean of scale as possible. If they are heated to redness in preheating, of course fresh scale will be formed. But the operator should begin by cleaning his pieces with sand blast or sand-paper or by tapping.

As with ordinary blacksmith welds, it is also important to rid the joint of grease by mechanical means or by scouring it with dilute alkali.

Preheating.—It is necessary to heat with a torch all pieces about to be joined, for the reason that the molten thermit must

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meet a hot responsive surface of metal when it flows into the mold. If poured into a cold mold and on to a cold joint, the thermit may be chilled enough to make it flow slowly and imperfectly. The result will be an imperfect junction, and the shoulder of the weld may be full of air-holes and minute cleavage planes from rapid cooling. Do not rely on the great heat of thermit, but preheat in all cases except butt-welding.

For most work a gasoline or benzene torch is good enough. The flame is fairly neutral and will not form scale very fast.

For heating very large pieces, several torches are often needed. In shop repairing, producer gas may be used; and in this event the burner can be made to give a reducing flame, which will prevent scale from forming.

As to temperature, the joint should be at least hot enough to vaporize water drops with violence. It is well to heat the joint to redness where it can be done. But where the pieces are large, they will conduct the heat away from the part where the flame is playing; the operator must be satisfied with a temperature ranging about 300 deg. Cent.

Safe-guarding the Mold.—Bear in mind that liquid thermit is exceedingly fluid—as much so as warm molasses—and as it is much heavier, it will search diligently for all openings in the mold. For this reason the mold must be tight at the entering of the iron pieces. The operator should have at hand a bucket of *luting clay*, made of equal mixtures of fire-clay and sand, made pasty with a little water.

If the molds are solid pieces, as in rail and locomotive-frame welding, he smears a thin layer over the surface of the molds where they come in contact with one another. This will make a fairly tight mold.

Also he must stuff luting clay around the mold where the iron pieces enter, otherwise the thermit may find its way along the iron and spurt out. The danger of an unexpected squirt of thermit need not be dwelt on.

When the mold is made of fire-clay tamped over a wax collar, there should be no leaks if the operator is careful. He must be sure that his mold is rigid and strong enough to hold the extra weight of the pour.

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A possible overflow of thermit and slag must be provided for. Large pours of thermit are always made with this in mind. If the pour is made in the workshop, the floor should be of sand and the workman should remove his tools before tapping. After tapping the thermit he should remove himself as quickly as possible.

Amount of Thermit.—As has been stated elsewhere, there should be twice as much thermit steel poured for a weld as is necessary to fill the space between the joined pieces and to provide for shoulder around the joint. The first of the thermit pour that reaches the inside of the joint expends most of its heat in raising the temperature above redness. It passes up the riser, leaving the interior so hot that the last of the pour settles easily around the half-molten joint and is fluid enough to make a homogeneous casting.

The *amount* of the *thermit* powder used in a weld is *eighteen times* the unoccupied space in the mold after the joint is adjusted and ready to weld. The thermit is estimated in ounces, the space in cubic inches (page 124). This number, eighteen, provides twice as much thermit steel as is needed for the weld, the rest, as already stated, going into the riser. However, P. Redington[1] and H. L. Des Anges[2] advise that *three* or even *four* times the amount of steel is needed to get the best results. This may be due to imperfect preheating.

The Reaction.—The reaction is rapid and violent. There is no explosion, but the crucible sends up a shower of sparks much like the kind of fireworks called a "flower-pot." So to prevent this and to conserve the heat, a loose metal top is slipped over the crucible as soon as the fuse is lit.

The workman should use smoked or colored glasses to protect his eyes.

The reaction takes not longer than thirty seconds. The crucible should not be tapped for at least ten seconds thereafter, because the reaction has left an intimate mixture of slag in steel in the crucible, and a little time is allowed for the slag to float to the surface.[3] I believe that outside of insufficient perheating, one

[1] *Foundry*, April, 1905.
[2] *Foundry*, August, 1905
[3] *Ibid.*, R. Webb, July, 1905.

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of the common causes of failure of thermit welds is premature tapping.[1] No steel is strong if it is premeated with slag.

After Pouring.—After pouring, you have an ordinary steel casting, with this exception—that the heat of the joint will be conducted by the body of the part much faster than is good for a steel casting. If you are welding a fractured locomotive frame, and you want to assure yourself that the joint will be as tough as the frame, you had best give the joint several hours' annealing by such means as are at hand.

Annealing is not so necessary in a thermit joint as it is in the oxy-acetylene and other welds. Thermit steel shows a low-carbon content. Rapid cooling will not temper it highly. But no chilled steel is as tough as the annealed product. Tests in practice seem to show that after-heating gives an even-grained and tougher joint.[2]

The results of after-heating may be attained in a lesser degree by keeping the mold in place until the joint is cooled. Cooling may take several hours with the mold on if the pieces are large.

Nickel Addition.—Nickel thermit is an allied substance to thermit proper. It is a mixture of nickel oxid and aluminum, and the reaction sets free the nickel in the metallic state.

$$3NiO + 2Al = 3Ni + Al_2O_3.$$

If the operator wants a higher tensile strength without diminishing his elastic limit, he introduces a can of nickel thermit into his ladle of molten iron, as already described. Or the nickel thermit is fired in a hand-ladle, using a small quantity, and pouring in the remainder of the package gradually as the reaction progresses. The entire contents of the hand-ladle are poured into the big ladle, which should be one-third full of molten iron. The big ladle is then poured full of iron and a can of titanium thermit is poled in to cause a thorough mixing of the iron and nickel.

One per cent. of nickel is sufficient to increase the strength of ordinary iron about one-third. Two per cent. of nickel thermit gives a little more than 1 per cent. metallic nickel.

[1] *Foundry*, Jas. F. Weber, July, 1905.
[2] *Journal U. S. Artillery*, Gustav Reiniger, July–August, 1907.

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Metallic nickel is also added to thermit, using 5 ounces nickel to each 100 pounds thermit if you wish to make a 1 per cent. alloy.

Titanium Addition.—Titanium thermit is another "alumino-thermic" substance having the reaction

$$3TiO_2 + 4Al = 2Al_2O_3 + 3Ti.$$

It is introduced into the ladle in foundry practice for the purpose of purifying the iron. About 1 per cent. is recommended. As its office is to reduce the sulphur and nitrogen, most of it reappears in the slag. Its effect is to greatly increase the strength, presumably by making the metal close-grained and homogeneous.

Butt-welding of Pipes.—One of the unique applications of thermit is in the butt-welding of pipes and bars. It is a very difficult and often impossible thing to make a strong joint of two gas or water pipes without cutting reverse threads on the two and using a sleeve union. Welding such joints by ordinary means is generally out of the question, because with the facilities ordinarily at hand, it is difficult to obtain the right welding heat, and almost impossible to keep the surfaces clean enough to join them.

In using thermit for butt-welding, the slag of the thermit reaction is poured into the mold before the metal. It covers the iron surface in a thin layer that is at once chilled and adheres to the metal. This coating of slag serves as a distributor of the heat of the thermit metal to the iron, at the same time preventing direct contact of the thermit metal with the pipe. As soon as the operator believes the pipe ends are plastic, he pulls them tightly together, and the weld is effected.

As this is a very practical and necessary weld, it will be well to explain the operation and the appliances in detail.

Suppose two 1-inch abutting gas pipes are to be welded. The ends are first cut square and filed to smoothness, so that when the pipes touch their ends shall fit closely all around. Clamps are then fitted on the pieces, about 5 inches from the ends, and screwed tightly on the pipes. These clamps have sockets for two connecting draw screws, which are fitted in place and

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tightened with pins (see Fig. 74) until the pipe ends touch. Brace the pipes so that they align as they should and place the lower mold jaw under the joined ends of the pipes, so that the line of joining is in the middle of the mold. This mold is a hinged affair, having two handles, and resembles a nut-cracker (see Fig. 75).

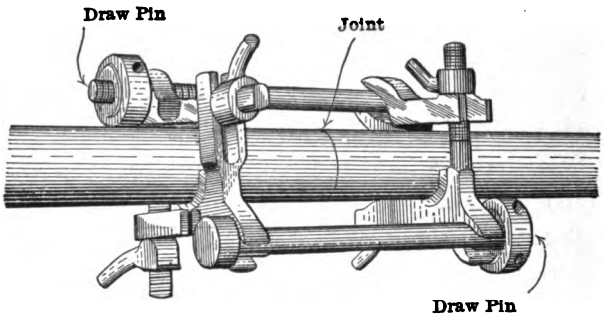

FIG. 74.—Clamps in position. Pipe-welding by thermit.

The thermit portion, about 2 pounds, is poured into a small cup crucible, which is lined with magnesia and operated with a pair of tongs. Allow the crucible to stand half a minute after firing, so that the slag and steel can separate. Then pour over the lip of the crucible so that the slag comes out first. Begin pouring at one end of the lip of the mold and travel to the other end. As the thermit slag is poured in on a cold surface of pipe,

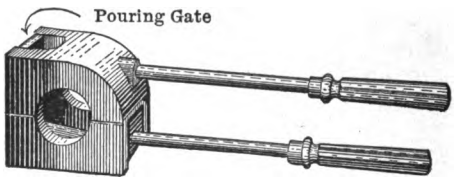

FIG. 75.—Mold for pipe-welding with thermit.

it forms a hard shell around the metal, and the liquid which follows distributes its heat evenly through this shell, which is a poor conductor. During the pouring, the operator's assistant presses the handles of the mold together to keep the mold in close contact with the pipe. About one minute's time is allowed for the iron of the pipe to reach welding heat. The draw pins are

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put in the sockets of the clamps and screwed tight. If the pipe ends are plastic and ready to weld, the operator can feel it by screwing the draw pins. The nuts on both pins are given two full simultaneous turns by the operator and his assistant. This is enough to force the pipe ends together and complete the weld. If the operator desires, he can force enough metal into the upset by giving the draw nuts another turn, to make the joint considerably stronger than the pipe itself.

The mold is taken off at once by tapping the upper jaw loose with a hammer. The slag collar which adheres to the pipe is knocked off carefully, and the red-hot joint is allowed to cool.

The draw bars and clamps which held the pipes together are removed as soon as the weld is cooled. The joint will have a slight upset due to the extra metal forced into it. This may be machined off if necessary.

Tests on such a weld will give a fracture or a crease in the pipe outside of the line where the mold fitted.

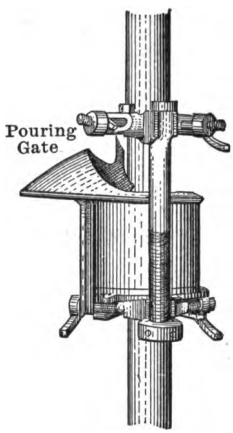

FIG. 76.—Clamps and mold in place for welding vertical pipe.

The foregoing weld was made on a horizontal piece of piping. For an inclined or vertical piece, the apparatus and process are the same, except that the mold will have its mouth placed in the side so that the thermit can be poured in when the mold is in place (see Fig. 76).

For pipes or rods of different thickness or diameter, the size of the mold will vary, also the amount of thermit to use and the time it takes to raise the joint to welding heat. The manufacturers supply both molds and clamps for pipes and rods of standard sizes, and specify the amount of thermit to use in each case.

In this application of thermit, it should be noted that the thermit steel does *not* come in contact with the pieces to be welded, nor does its substance form a part of the weld. Accordingly, thermit butt-welding is applicable to pipes and rods of wrought iron and mild steel, and *not* to cast iron and high-carbon steel.

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This process can be used for welding gas and water pipes while in the ground; steam and ammonia and compressed-air pipes; pipe coils, before or after bending; steel rods in reinforced concrete.

The entire cost of making one weld for a pipe of 1-inch bore is approximately $22. This includes the total cost of the apparatus necessary, and the time charge of one hour at thirty cents for the operator and twenty cents for the helper. This prohibitive cost is rapidly reduced for welds in number, just as the cost of a printed page rapidly decreases as the number printed increases. One hundred welds like the above would cost, approximately, one dollar each, supposing that two welds could be made per hour. The first cost of tongs and clamps is final, while the crucible must be replaced after about ten firings and the mold after fifty welds. The cost of the thermit and the ignition powder and also the labor is a constant.

One of the rivals to this welded joint is the plumber's sleeve joint. In comparing the two methods of joining, the contractor must consider several things; will it be cheaper to cut a thread on each pipe end and sleeve the joint? Also, will it be possible for the workman to get at his joint to cut the thread? Is a leak at the joint going to be a vital matter? A weld cannot leak, while any other joint is apt to under pressure, especially where the pipes are cold, as in ammonia plants. Will a sleeve joint be strong enough in cases where the pipes are subject to strain? And, finally, how do the total costs compare? This last will depend largely on the number of joints to be made.

Another rival is the oxy-acetylene-blowpipe weld. It is probable that with this method one workman can make from one to four welds an hour, depending on the amount of labor he must put on cutting and fitting the pipe ends preparatory to welding. This, together with the cheapness of the gas used, makes the operating cost much less than the thermit butt-weld. However, the cost of the apparatus, two gas storage tanks, the blowpipe, and the checks-valves is much greater. Also, to travel from pipe to pipe, often necessary, the operator would need an assistant to carry the heavy tanks, etc.

Butt-welding of pipes can be done by the Thomson electric

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process. But this process is at a disadvantage here because the welding must be carried on in a heavy machine. Whereas, when pipes are to be butt-welded, the chances are that they are in some out-of-the-way corner of a room or cellar and cannot be taken out.

Mending Defective Castings.—Besides its use in welding, thermit is being exploited for the repair of defective castings, which is not strictly a welding operation. Also for raising the temperature of the ladle before pouring for castings; for poling "burnt iron"; for the introduction of nickel, titanium, etc., into molten iron; for the formation of alloys; for the reduction of the less common metals from the refractory ores and earths. Though these last have nothing in common with welding, they will be treated of briefly, so that the treatise on thermit may be complete.

In the foundry, in the casting of large and expensive pieces, the loss by defective castings is sometimes equal to the price asked for the casting, due to cracks, bad flows, breaks, and inopportune blow holes. If the foundryman can save such pieces from the melting pot, he will greatly increase his profits.

For mending small surface defects, where the idea is to replace the surface without regard to the strength of the patch made, the following method is advised. First, chip out the defect to be sure that it is superficial. Heat the casting around the hole to a red heat. Then bank a basin of sand around the hole. Place a piece of abestos in the bottom of the basin, large enough to cover the hole. Pour thermit powder into the basin, using 18 ounces of thermit for every cubic inch estimated space of hole in the metal. If the casting is a large one, use a greater percentage of thermit, as more heat will be needed. Fire the thermit, and it will quickly melt the asbestos bottom, and the molten steel will be deposited in the hole in the metal. When cool, the protruding metal is machined off.

This reaction is too rapid for the complete separation of the slag, some of which may be lodged on the junction of the thermit metal and the casting. Also, it is likely that the local heating will cause weakening stresses in the patch when it cools; while it may also be full of blow holes if it cools rapidly, because of

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conduction. It is claimed[1] that the shrinkage is so great that such a repair is unsafe and useless.

Thermit may be used for repairing fractures in castings before they leave the foundry. If the casting have a piece broken cleanly

FIG. 77.—Thermit can plunged into ladle.

off, this may be joined at a less cost than the cost of recasting. Also cracks may be drilled out and thermit used.

Thermit in Foundry Practice.—Thermit may be introduced into the ladle before pouring for a casting. If the piece to be cast is long and thin, or if it has intricate parts which require a very hot metal to produce, the temperature of the iron in the ladle can be raised by plunging a can of thermit into it and holding it at the bottom until both thermit and can have burned up and the slag has come to the surface. The excess heat of the thermit will raise the temperature of the ladle (Fig. 77).

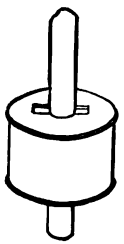

FIG. 78.—Detail of thermit plunger can.

How much thermit to use for a given amount of iron cannot be stated definitely—probably 5 per cent. It depends on the initial temperature of the ladle, the demand of the casting, and the *cost*. The cost prohibits its use except for special work, such as the casting of stern-posts for ships, and the production of small castings which can be made at any time without the capital investment for a special converter plant.

[1] "Mending a Casting with Thermit," Pat Redington, *Foundry*, April, 1905.

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The company also recommends placing a can of thermit in the riser of such a casting as a ship's stern-post. If the post is to be a long one, "the metal cools very rapidly during its passage through the mold, and becomes so sluggish that the pressure of the runner is not sufficient to force the metal up the rising heads more than one-half of their length." The thermit can will reinforce the heat of the rising metal.

To prevent "piping" of steel ingots, a can of thermit may be plunged into the ingot. The operator waits until the ingot has

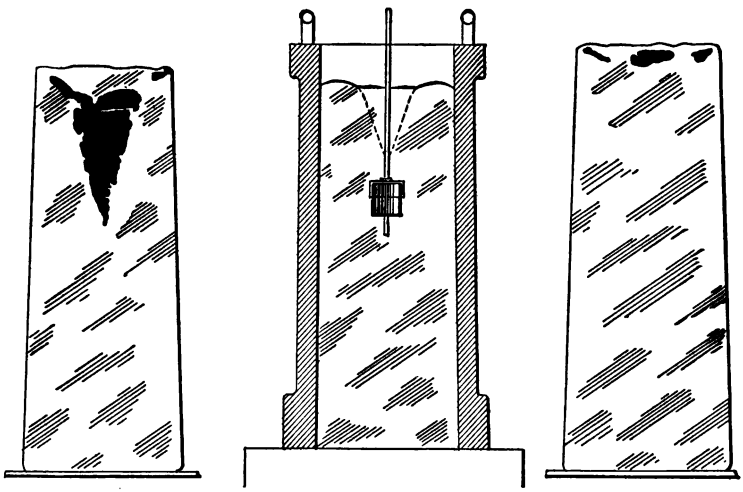

FIG. 79. FIG. 80. FIG. 81.

FIG. 79.—Steel ingot showing defective head piping without anti-piping thermit.
FIG. 80.—Showing ingot with box of anti-piping thermit in position.
FIG. 81.—Ten-ton steel ingot having been treated with anti-piping thermit.

begun to solidify. The "pipe" will then begin to form, due to the chilling of the steel on the outside and its contraction. Break through the top crust, and thrust the can well down into the ingot. It will ignite and raise the temperature of the upper part of the ingot to remelting. A solid ingot will result (Figs. 79 to 81). This is another use for thermit, questionable, because of its cost.

Poling.—As has been described, the foundryman often freshens his "burnt iron," by stirring the ladle with a green stick of wood. "Burnt iron" contains oxygen in the form Fe_2O_3. This oxid of iron impairs the strength of the iron very much.

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By stirring the molten mass with a green limb, the workman has added carbon which reduces the iron oxid, as follows:

$$2Fe_2O_3 + 3C = 4Fe + 3CO_2.$$

The limb being full of water also throws out steam which causes the iron to boil. This makes the reaction complete throughout the mass. When the oxid is all reduced, the ladle is "fresh." But this operation, called "poling," lowers the temperature. Now "poling" can be done with a thermit can on the end of a rod instead of with a green limb. The composition of the thermit must be varied so as to have a positive effect on the oxid of iron; that is, there must be a slight excess of aluminum. Thermit "poling" has the advantage that it raises the temperature of the molten iron. But it should not be used except in ladles of steel, because at the heat of molten steel there is complete reaction with the excess aluminum in the thermit. While at the lower temperature of molten cast iron, the reaction would be confined to the thermit can. The excess of aluminum would not react on the iron oxid of the burnt mass, and both would stay in solution. In other words, the iron would be poorer than ever.

A better method recommended by the company is the use of manganese with the thermit, though no doubt the thermit can be omitted if we do not wish to raise the temperature. Pure manganese, made "thermochemically," can be used. Manganese, in the form of ferro-manganese and spiegel, have long been known to furnace men as a cure for "burnt iron" and a toughener of their product.

W. M. Carr[1] is authority for the statement that a large ladle can be used for a small converter if thermit be added to the first pour in the ladle immediately preceeding the second pour. The ladle held 5 tons, the converter 2 tons, the pours were forty-five minutes apart. The thermit was poled into the first pour, as usual, in a can on a rod. It freshened the iron and raised its temperature to about that of the second pour.

Adaptability.—In summing up the thermit process as a whole it will appear that it is especially suited for welding and repair-

[1] "Development of the Thermit Process in Foundry Practice," *Foundry*, July, 1906.

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ing large pieces. In pieces ranging below 4 square inches cross-section, it has to meet competition with the oxy-acetylene, oxy-gas, oxy-hydrogen, electric, and smithing processes. Its application to butt-welding is very often the cheapest, handiest, and most workmanlike.

In rail welding it has to compete with the electric process, which was the pioneer in this field.

In welding motor cases for steel cars it has to compete with the oxy-actylene process.

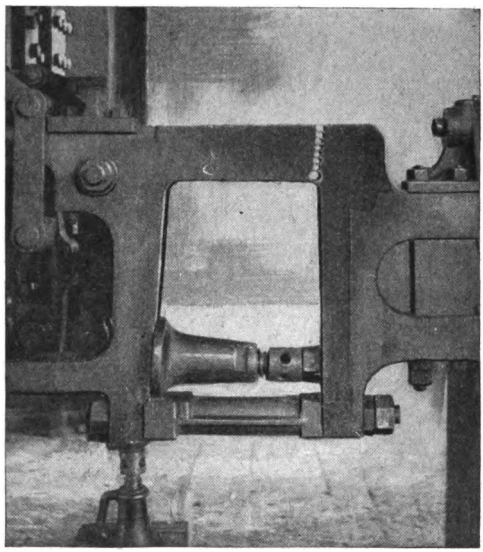

FIG. 82.—Fracture on locomotive frame, opened up by drilling and held in place by jacks in preparation for thermit welding.

In welding fractured locomotive frames it is used with success, and is evidently as cheap as can be had—certainly, much cheaper than the old blacksmithing, for the weld may be effected often without dismantling. It is used in their repair shops by many of the railroads in this country and abroad for repairing engine frames and also driving rods and spokes, and occasionally the repair machinery. The Central Railroad of New Jersey first introduced thermit in their shops.

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It is used for occasional repairs of fractured gun-carriages and parts.

Also for crank shafts, embossing dies, shears, and anvils, in cases where it is cheaper to repair than to replace.

For broken rudder and propeller shafts, skegs, and stern-posts of vessels it is invaluable. This is the most notable feature of the process. Before the advent of thermit, a break in one of the parts named meant the dry-docking of the vessel for weeks, the displacing of the part broken and its repairing at great expense and trouble, or sometimes its displacement. Besides the actual expense entailed, much was lost by having the boat out of commission.

Since the use of thermit for such repairs, dry-docking is still necessary, but the whole operation can be gone through with in much less than a week; the vessel is not dismembered and the weld may be made the strongest part of the piece. Broken anchors can be mended in a few hours. As already described, there are many instances of such quick, cheap, and strong welds.

Thermit is almost a new subject. It has been known to the repair men since about 1904. It is already a definite success, and under the energetic experimentation of the Goldschmidt Co. it is likely to prove useful in ways at present unthought of. It is likely that special thermits will soon be invented for welding other metals than iron and steel.

Typical Welds.—In the welding of rail joints in quantity there are a number of large contracts that have come to notice. Among them the joining of the third rail of the Paris subway; the welding of 10,000 joints of the Electric Traction Company of Adelaide, Australia; the welding of the Lexington Avenue line in New York City. The latter was especially difficult because of the heavy traffic. It was impossible to do the job by daylight without tying up the traffic. In the early morning hours, when the cars run on a ten-minute schedule, the company succeeded in carrying on their welding with only the occasional holding up of a car.

The cost of thermit rail welding has been variously estimated. Track at Holyoke,[1] Mass., welded in 1904, cost $6.23 per joint. The longest unit rail made was 2300 feet. In the same year rail

[1] *Street Railway Journal*, Feb. 18, 1905.

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welding at Hartford,[1] Conn., cost $5.00 per joint, which figure includes repaving.

Among pipe-welding contracts, that carried out for the Manhattan Refrigerating Co.,[2] of New York City, is noteworthy. Their entire system of piping was welded by the thermit process. There were twenty-nine 1 1/4-inch joints, and twenty-seven 2-inch joints, both under a cold pressure of 180 pounds. The result is reported as successful. This is a decided improvement on the sleeve joint for ammonia systems, because the contraction of the pipes due to the extreme cold is certain to allow leakage in the sleeve joint.

Repair of the "Betsy Ann"[3]

"One of the quickest repairs on record was accomplished on the Mississippi River Steamship 'Betsy Ann,' belonging to Learned & Son, Natchez, Miss. This is a stern wheel boat, the shaft being a hexagonal one, 8 3/5 inches on the inscribed circle and over 23 feet long. A crack developed on one of the faces and ran down a short way on the second face, the total length visible being about 4 inches. Attention was first called to this by rust showing through the paint and after examining the shaft carefully it was decided to run the steamer to see if the crack extended. Within a short time it was noticed that the crack had extended 3/4 inch since the first observation, and it was therefore decided that a repair of some sort should be made on it at once. Preparations were made to weld a collar of Thermit steel around the shaft at the fracture and thus to restore it to its original state of usefulness. A pneumatic chipping hammer was used for cutting away the metal to the bottom of the flaw, so that the superheated Thermit steel could be led to the deepest part. After this had been accomplished, the paint was cleaned off a distance of 5 inches on either side of the fracture and the weld effected by the wax pattern method, as previously described; 416 pounds of Thermit, 35 pounds of mild steel punchings, and 8 pounds of metallic manganese being required. After

[1] *Ibid.*, Jan. 28, 1905.
[2] *Iron Age*, Nov. 16, 1905.
[3] *Reactions*, published by Goldschmidt Thermit Co.

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allowing five hours for the metal to set, the mold box was removed and the weld found to be so satisfactory that the steamer immediately proceeded on her trip without waiting for the gate and riser to be cut off; in fact, the repair was accomplished without causing the steamer to miss a single trip."

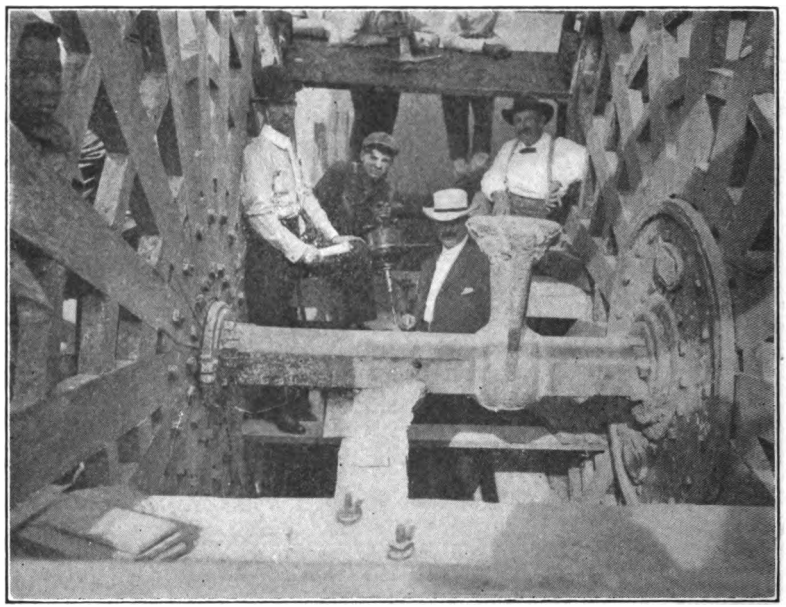

FIG. 83.—Finished weld of S. S. "Betsy Anne" before removing metal left in gate and riser.

Repair on Steamship "Corunna"

"This was a vessel of 1296 tons register, 240 feet long, 35 feet beam and 21 feet depth. In getting away from her pier in the Lachine Canal, Montreal, the stern of the vessel was caught by the current and swung against the stone walls of the canal, the shoe or skeg being broken off close to the keel, while the rudder-post was broken at a point about 10 inches from the top of the rudder. Owing to the serious nature of the injuries it ordinarily would have been necessary to tow the vessel to Cleveland (there being no adequate dry-dock in Montreal to make these repairs in the usual way).

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"It was soon decided that, without doubt, several thousand dollars could be saved by repairing the frame and rudder-post with Thermit.

"On inspection it was found that the rudder-post was broken off inside of the tube, while the stern frame had been bent 12 inches out of line, the shoe being completely broken about 13 inches from the central line of the post. On account of the break in the rudder-post being by an old scarf weld, fully 11

FIG. 84.—Finished weld on rudder post of steamship "Corunna."

inches in length, it was not deemed advisable to attempt to weld this again, so about 14 inches of the rudder-post adhering to the rudder was cut off and a new piece of shafting, 8 feet long, welded on in place of the old post, as shown in the illustration. In order to facilitate the operation, the rudder was removed from the ship and the post welded on shore, this being done to prevent interference with the operation of welding the stern frame.

"It being necessary to have a supply of compressed air in order to operate the gasolene torch and pneumatic tools, an old Westinghouse steam-driven air-brake compressor was obtained

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and mounted on board ship, the steam being piped from a donkey boiler. A receiving tank was placed on the edge of the boiler and piped to the compressor. With the apparatus in place, preparations were made to effect the welds in the usual way, the rudder-post weld being reinforced by a collar 3 inches long and 1 inch thick, while the stern-post was reinforced with a collar 8 inches long, 1 inch thick at the top and sides, and 3/4

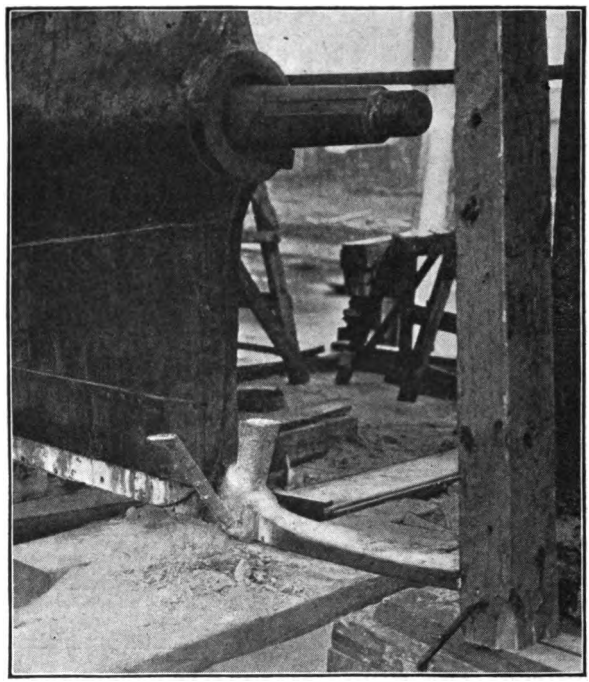

FIG. 85.—Thermit weld on stem post of steamship "Sochem."

inch thick at the bottom; the latter being done in order that the draught of the vessel might not be made any greater than could be helped. One hundred and fifty pounds of thermit, 25 pounds of steel punchings, and 3 pounds of metallic manganese were used in welding the rudder-post, while 350 pounds of thermit, 70 pounds of steel rivets (1 by 3/8 inch in size) and 7 pounds of metallic manganese were required for welding the stern frame.

"While the total time required for the operation amounted to

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five working days, there is little doubt that had the work been done in a properly equipped dry-dock, it could have been accomplished in three days or less."

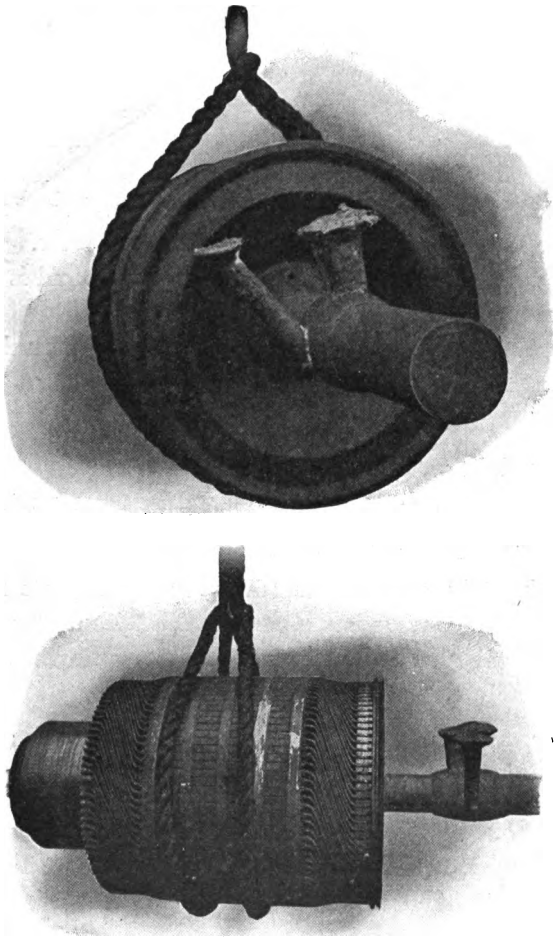

FIG. 86.—Weld made at shops of the central railroad of New Jersey on a motor armature shaft.

Weld of Electric Motor Shaft

"It has usually been deemed necessary to leave a reinforcement or collar of thermit steel around the various welds made by the thermit process. An instance has occurred recently,

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however, where this reinforcement was machined off and the weld subjected to very severe strains, but without causing any weakness to show up.

"The case in question is that of an armature shaft 3 inches in diameter, 14 1/2 inches long, and required to transmit 50 h.p. to the main hoist of a 50-ton Shaw electric crane.

"The weld was made in the shops of the Central Railroad of New Jersey, Elizabethport, N. J., and the armature has now been in service since October 8 and is giving perfect satisfaction in spite of the fact that all the surplus metal about the weld was machined off and the shaft turned down to its original diameter.

"The weld was made 9 inches from the hub, and is shown in the accompanying illustrations" (Fig. 86).

Chemistry and Thermics.—The chemical formula for the present thermit reaction is

$$8Al + 3Fe_3O_4 = 9Fe + 4Al_2O_3.$$

Expressed in weights, it is

217 parts aluminum + 732 parts magnetite = 540 parts metallic iron + 409 parts slag,

or, approximately, 3 parts of aluminum and 10 parts magnetite will produce, on combustion, 7 parts metallic iron.

Commerical thermit is a mixture of finely granular aluminum with less finely granular magnetic iron scale. The aluminum is about the fineness of granulated sugar; the scale is like coarse sand. The ratio by weights is three of iron scale to one of aluminum. Dr. Goldschmidt began his experiments with similar mixtures about 1895. Thermit was not heard of before 1902. He speaks with feeling of the mechanical and chemical difficulties that hindered the perfection of his ideas. So there is good reason to suppose that the thermit mixture is about the best that can be made, both in its physical form and in its reaction. The difficulties that confronted Dr. Goldschmidt were:

1. The violence of the reaction.
2. How to get a good homogeneous steel out of the reaction.

One of the troubles with thermit reactions is their violence. The burning of several metals, as calcium, is so brisk that the contents of the crucible boil over and metal and slag alike are

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lost. Probably for this reason the magnetic oxid was substituted for the hematite oxid. Early literature gave the reaction as

$$2Al + Fe_2O_3 = Al_2O_3 + 2Fe,$$

but Dr. Goldschmidt[1] gives the present reaction as between aluminum and magnetite, and a casual examination of thermit by means of a magnet shows that magnetite is now used. It is likely that the magnetic oxid gives a slower burning than does the sesquioxid. The magnetic oxid is made of granulated rolling-mill scale.

The aluminum is powdered by a secret process. At present there are two known ways of pulverizing metallic aluminum. The first is to raise the metal to an approximate 600 deg. Cent., at which heat the metal becomes brittle and granular, and can be ground between rolls. The second way is to blow air through red-hot aluminum so as to partly oxidize the metal. It is then cooled to about 600 deg. Cent. and ground, the oxid of aluminum helping to separate the metal into fine granules.

As will be guessed, a small amount of thermit will burn more slowly than a large amount. The heat of a large burning, such as for repairing a propeller shaft or large engine fly-wheel, will be so intense that the crucible will boil and throw out part of its contents. To prevent this, from 5 to 15 per cent., by weight of thermit, of cold steel billets and turnings are added to the thermit before burning. This iron takes up the excess heat. Of course this added steel must be of correct chemical composition.

While it is important to keep down the boiling reaction, it is even more necessary to get a resultant steel that will be strong, elastic, and dense. The quality of the thermit steel will depend on its chemical composition. Good steel is low in sulphur, phosphorus, and silicon, and not too high in carbon. The following "Average Composition of Thermit Steel" is given by the Company:

Carbon	0.05 to 0.10
Manganese	.08 to .10
Silicon	.09 to .20
Sulphur	.03 to .04
Phosphorus	.04 to .05
Aluminum	.07 to .18

[1] *Electrochemical and Metallurgical Industry*, Sept., 1908.

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Of course, to produce a steel of the above composition, the aluminum and iron scale that make up the thermit must be very pure. It would be a problem to obtain sesquioxid of iron of sufficient purity and at the same time as cheap as rolling-mill scale. Sesquioxid or hematite ore always contains one or the other of the impurities in considerable extent and is of variable composition; while, in using scale from Bessemer or open-hearth steel the impurities would be already known and would be much lower.

In regard to the proportioning of the mixture, the formula calls for 3 parts of aluminum to 10 of iron oxid; the thermit mixture is 1 of aluminum to 3 of the oxid.

In nickel thermit the reaction is $2Al+3NiO=Al_2O_3+3Ni$. By weight, it is 54 parts aluminum and 224 parts nickel oxid give 176 parts metallic nickel. Or, approximately, 1 part aluminum and 4 parts nickel oxid give 3 parts metallic nickel. Nickel thermit, however, contains 5 parts of nickel oxid by weight to 5 of aluminum.

Besides the aluminum-iron oxid reaction, a number of others have been and are being tried. It is possible that the future thermit may dispense with aluminum and substitute another metal for reducer. "Weldite," an English product, uses silicon and aluminum with Fe_2O_3. Dr. Goldschmidt himself has tried other combinations: for instance, aluminum and calcium, which, according to Dr. Richards,[1] give a greater heat due to the formation of calcium-aluminum slag. He gives the probable formula

$$5Fe_2O_3+3CaAl_2=3(FeO.CaO.Al_2O_3)+7Fe;$$

and claims that 70 per cent. of the iron would be reduced from its oxide; and that one part calcium-aluminum alloy will produce one and four-tenths of liquid iron (metallic).

Calcium[1] alone can be used to replace aluminum, but the reaction is so violent that sometimes the contents fly out of the crucible. The addition of 30 to 40 per cent. fluor-spar (CaF) or 10 to 20 per cent. quicklime (CaO) gives a saner reaction.

Heat of Reaction.—Richards[2] has calculated the heat of the thermit reaction as 2694 deg. Cent. The temperature commonly

[1] *Engineering and Mining Journal*, June 15, 1907.
[2] *Electrochemical and Metallurgical Industry*, J. W. Richards, June, 1905.

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given by the manufacturers is 3000 deg. Cent. M. Féry, using his new radiation pyrometer, found the temperature of the stream of steel as it flowed from the crucible to be 2300 deg. Cent—probably about right when one makes allowance for the chilling effect of the crucible. Taking the melting point of steel as roughly 1350 deg. Cent., the thermit steel is nearly twice as hot.

Testing.—The strength of an ordinary weld in wrought iron varies from 10 to almost 100 per cent. of the strength of an equivalent cross-section of the metal. In general, however, a weld made under proper conditions runs between 50 and 70 per cent. for high-carbon iron and between 60 and 80 per cent. for low-carbon iron. The strength of a thermit-weld is subject to quite as great variance, for the reason that thermit steel is a definite compound and may be of quite different composition from the parts welded by it. Also it is well to bear in mind that the initial strength of thermit steel itself is subject to variations due to the amount of included slag, air holes, and to the rapidity of cooling; also, the chemical composition can be varied by the addition of alloy formers, such as nickel, chromium, and manganese; and the addition of titanium and manganese in small quantities, which are purifiers.

A number of tests of different character have been made by the company and by railroad and repair shops, some of the results of which are given as follows:

Test No. 1.[1]

"At the St. Louis and San Francisco Railroad shops, Springfield, Mo., recently the following test of a thermit-weld was made:

"A section of a cast-steel frame, 4 by 5 1/2 inches, was welded by the thermit process. In making the weld 75 pounds of thermit, 12 pounds of punchings, and 1 1/2 pounds of manganese were used. For molds, fire-brick was used, cut to shape.

"After the weld was cold, the collar on the bottom and one side was planed off 1/4 of an inch below the original surface of the casting, in order to show the place where the two metals had joined. The riser also was cut off, leaving the collar, however. The weld was absolutely solid, not a single blow hole appearing anywhere—not even the riser.

[1] *Reactions*, Vol. I, 1908, published by Goldschmidt Thermit Co.

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"The welded section (now 3 3/4 x 5 1/4 inches), with collar 1 inch thick on top and on one side, was then placed in wheel press on supports 14 3/4 inches apart and a piece of hardened steel, 1 inch square, placed as shown in figure 87.

"A pressure of 170 tons was applied before breaking. The fracture started at the bottom outside welded section, extending into the center of the weld at the top. The fracture showed that perfect amalgamation of the metals had taken place.

"In comparing the strength of this weld with original stock, assuming a maximum stress in the outer fiber for cast steel of

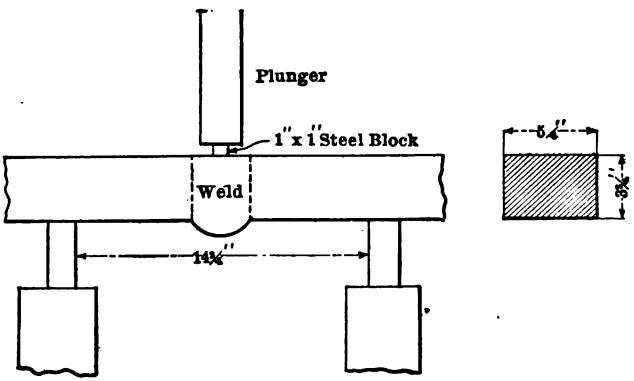

FIG. 87.—Arrangement of test piece for test No. 1.

60,000 pounds to the square inch, a section 3 3/4 x 5 1/4 inches tested in the same way would break at 100 tons."

In this test No. 1 it is presumed that the 12 pounds of punchings were mild steel. The manganese was used to freshen the iron, and most of it probably slagged as manganese oxid and came to the surface.

Test No. 2. [1]

"Two test bars taken from the upper part of a previously, but unsuccessfully, poured casting gave, on an average, 66,000 pounds per square inch tensile strength and 9.5 per cent. elongation on a measured length of 2 inches. This casting showed in all the sections a clean, non-porous, dense grain. It appears possible, therefore, to produce steel castings of thermit and, in a

[1] *Iron Age*, April 26, 1906.

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case of necessity, the higher price would not be of importance." * * *[1]

Test No. 3.

The thermit process has been used by the Fore Shipbuilding Co.,[1] of Quincy, Mass., who have made a number of tests of the physical properties of thermit metal. Bars of rolled steel, of section 2 x 4 1/2 inches were drilled, broken, and welded with thermit. Standard test bar were cut from the centre of the welded bar, and were submitted to the ordinary tests. As the test pieces were of uniform size, both in the stock and the welded section, the result is worth recording:

	Elastic limit	Tensile strength
Weld	32,000	59,000
Stock	38,000	60,500
Weld	33,700	61,800
Stock	36,850	63,400

It is to be noticed that the tensile strength is 12.7 per cent. less in the weld than in the stock, and the tensile strength 2.5 per cent. less—a fair showing.

Test No. 4.—By the Illinois Steel Co., Chicago.[2]

C	0.05
Mn	.10
Si	.204
S	.04
P	.05
Al	.18

Tensile strength ..... 59,320 lbs.
Elongation ..... 25.33 per cent.
Contraction of area... 59.9 per cent.

Test No. 5.—By the Pennsylvania Railroad, Altoona, Pa.[3]

C	0.102
Mn	2.330
Si	1.227
S	.034
P	.07

Tensile strength ..... 91,600 lbs.
Elongation in 8″ ..... 21.5 per cent.
Silky fracture.

[1] *Journal United States Artillery*, Gustav Reiniger, July–August, 1907.
[2] *Transactions of the Society for Testing Materials*, E. Stutz, 1905.
[3] *Transactions of the Society for Testing Materials*, E. Stutz, 1905.

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Test No. 6.—It has been suggested that the thermit-weld may be strong in itself, but that it weakens the adjacent iron. To find if this is so, a section of welded rail was subjected to equal blows by a steam hammer, both on the unaffected rail and on the metal nearest the weld. The die used was a blunt tool, 1/4 inch in diameter. Measurement with a micrometer showed a depression of 0.1432 inch in the rail nearest the weld and 0.1596 inch 3 feet from the weld.

Tests, under varying conditions without number, might be multiplied. But for the practical man, those already given show that the ultimate strength of the thermit steel in practice can be estimated as over 30 tons to the inch section. By practice, I mean the thermit steel produced for repair work, according to directions: thermit, about 5[1] per cent. mild steel punching, and about 2[2] per cent. manganese for purifier.

Annealing for 3 hours brings the elongation well over 10 per cent.

Addition of about 3[2] per cent. nickel raises the ultimate strength about 5 tons without decreasing the elastic limit. Further addition of about 2[2] per cent. of chromium with the nickel brought the elastic limit to about 47 tons—as high as can be wished. Addition of 1 per cent. titanium raises the tensile strength. Tests have also been made of thermit steel that has been toned up with molybdenum, ferro-silicon, etc.

THE LAFITTE WELDING PLATE.

The Lafitte process was first heard of in 1905.[3] It may be described as the handy application of a patent fluxing sheet between parts to be welded, and can only be used for joining iron and steel. The flux is sold as a plate, size 4 by 8 inches and about 1/16 inch thick. This plate is composed of a preparation of calcined borax and iron filings, molded over a sheet of wire gauze. The gauze is about 15 meshes to the inch length.

[1] Calculated from weight of thermit powder.
[2] Calculated from weight of test bar.
[3] *Iron Age*, May 11, 1905.

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The iron of the wire is low-carbon (0.08 per cent. by color determination[1]).

The pieces to be welded are brought to the welding heat and forced together with a Lafitte plate between the contacts. As with all smith-welding, one of the contact surfaces should be decidedly convex, so that the point of it is first brought to bear on about the middle of the other contact surface. As the two surfaces are forced together, with the plate between, the borax melts and flows out, fluxing both surfaces as it flows. The iron gauze, which is inside the plate, is also partly melted and welds itself in place on both surfaces. It is likely that the strength of the Lafitte weld is as much due to the binding action of this low-carbon iron wire as it is to the complete fluxing of the borax. If properly done, the weld should be flawless. It is not necessary to use more of the plate than will cover both surfaces. The plate can be cut with ordinary shears.

From tests made it is claimed that the Lafitte weld is as strong as the metal, in case soft steel is welded; but that in high-carbon steel there is a slight lowering of the elongation and tensile strength (due no doubt to the reheating of a specially treated product).

In all but one of these tests the tensile strength is greater for the Lafitte weld than for the body of the stock, which may indicate that an upset of metal was crowded into the weld by the pressure of welding; while with cast steel the quality of the metal might be improved by the pressure.

Hard Steel Test

Mn, 1.35; C, 0.45; S, 0.045; P, 0.083; Si, 0.08

	Before welding	Lafitte weld	Common weld
Tensile strength, kg. .	70	63.6 68.	55.9
Elongation, per cent. .	15.2	10.0 11.6	2.5

[1] Specially analyzed.

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Test by the French Government[1]—(Toulon Arsenal)

	Tensile strength, lbs.			Elongation, per cent.		
	Before	Special compound	Lafitte	Before	Special compound	Lafitte
Iron on iron.....	48,700	44,729	48,938	16.33	9.66	14.33
Iron on soft steel.....	48,700	43,964	45,631	16.33	4.—	4.—
Steel on soft steel....	75,935	72,197	80,500	2.—	1.—	2.—
Iron on cast steel....	75,935	43,719	78,692	2.—	3.25	9.05
Cast steel on cast steel.	95,030	92,712	102,711	5.62	3.—	5.—

The Lafitte method may suggest itself for stock welds, such as the joining of axle parts and in chain making; in other words, in instances of multiple welding, where the pressure machinery is handy. It is most used in France and Germany.

FERROFIX BRAZING PROCESS

An ingenious and very good modern method of brazing broken iron parts (especially cast iron) goes by the name of the Ferrofix Brazing Process. It was devised by Frederick Pich, a German. By this process two fractured pieces of iron are cemented together with a thin film of brass which is so applied that it alloys with the iron surfaces, as deep as 1/16 inch. This was proven by cutting open a brazed joint and planing it down to ascertain its structure. To get this alloy in the joint, which is the secret of its strength, the solder must not melt below 650 deg. Cent.; hence hard brass is used.

Apparatus for Ferrofix repairing consists of:

1. A kerosene pressure tank and two or more Donnelly torches, which is an improved non-carburizing kerosene burner.
2. Fire-bricks and asbestos paper for a small furnace.
3. Ferrofix fluxing powder.
4. Patent brazing liquid.

The torch for heating may be air-coal gas, air-oil, oxy-acetylene, etc.

The flux is a mixture of equal parts of sodium carbonate and boric acid, with a little common salt to increase fluidity.

[1] *Iron Age*, August 24, 1905.

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United States patent paper, No. 688030, states that borax, the chief flux for all soldering and brazing, is troublesome because it swells up and falls off of the piece as soon as heat is applied. This, because it is then parting with water of crystallization. The patent flux, on the other hand, acts as follows: the carbonate is a ready absorbent of grease, of which it frees the the iron surface. With the application of heat, the carbonate also reacts on the boric acid, forming anhydrous borax and carbon dioxid. The borax is thus in close contact with the fresh metal surface, which it frees of rust and protects from the air.

The soldering compound is described in patent No. 647632 as follows:

"To form my improved soldering compound, I boil together finely pulverized borax and finely pulverized suboxid of copper, so that the same are intimately mixed and so that each particle of the suboxid of copper is surrounded, covered, and protected from the atmosphere by a thin film of the borax. Any desired proportions of the two may be used; but usually I take one-half of each, mixed with sufficient water to dissolve the same thoroughly by the boiling, and to cool down into a sort of paste.

"To use this soldering compound, the cast-iron surfaces to be soldered are cleaned by means of an acid in the usual way, fixed together, and the joints covered or surrounded with the compound. The joint is then heated, and therefore the borax melts and protects the cleaned surface of the iron against oxidization, removes any oxid thereon, and also protects the suboxid of copper against the action of the oxygen of the atmosphere. Consequently the suboxid of copper, likewise heated to a red heat, transfers its oxygen to the red-hot cast-iron surface, which oxygen combines with the graphite contained in the cast-iron surfaces to form carbon monoxid or dioxid, thus decarbonizing said surfaces, while the metallic copper becomes dissociated in a very finely divided condition. At the same time the hard solder is added, and as this solder, which is brought upon the surfaces to be soldered in the well-known manner, is likewise melted by the heat, it alloys itself with the incandescent particles of copper, and this new alloy immediately combines with the red-hot decarbonized soldering surfaces of the cast iron."

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The company also issue instructions, which are in brief:

1. "Clean fractured surfaces thoroughly with wire brush. If rusty or oily, burn off with torch.

"2. Mix Ferrofix powder with the brazing liquid to the consistency of paint and apply on the fractured surfaces with brush.

"3. Set casting to be brazed on fire-brick, in perfect alignment, using fire-clay to hold it in place (if it will not stay of its own weight). Be sure that the broken parts fit close. Build a furnace of fire-brick around the fractured part, allowing sufficient metal to be exposed, however, to absorb the heat. Leave top of furnace open, covering only with a sheet of asbestos—3/16 inch thick is sufficient ordinarily. The front of furnace should be left open to admit the torch blast.

"4. Place the torches so that the flame will come directly on fracture; bring casting up to a light cherry-red, almost straw. See that both sides of the fracture keep at the same color.

"5. Apply flux with a steel spoon (made from 3/8-inch Bessemer steel rod flattened out at one end) holding it at the fracture with the spoon, so that from the heat of the casting (not the torch alone) it will melt and disappear through the crack. As soon as it comes through freely and you can see the liquid flux underneath, apply spelter with a very little flux; feed this until it flows through thoroughly. With the spoon the melted brass can be taken from underneath and fed over until the crack commences to fill, then cut off immediately your air and gas, and keep feeding a little more new brass until it will not melt further by heat of casting. Allow to cool down by its own cooling.

"6. Clean casting with file, chisel, or emery wheel.

"The question of expansion and contraction is governed by the construction of the casting and the character of the metal. Care should be taken to see that heat is properly applied and distributed to overcome this feature. Experience on intricate castings is the best teacher."

This is another comparatively new process that is beginning to be known by the foundries, car shops, blast furnaces, and machine shops. The first patent dates 1900. Its success is based on its cheapness, handiness, and strength. The initial expenditure is very low, the burner costing most. The outfit

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would prove a great saving to any plant which has breaks in its iron machine parts. For a fractured piece could be mended in an hour, whereas it is ordinarily necessary to rivet the old piece together with side braces or to order a new piece under danger of delay and hold up.

As for strength, the company guarantees that the joint is stronger than cast iron; brazed pieces never break in the joint. Moreover, the pieces to be mended are set as closely as possible, as the spelter will penetrate the tightest fracture.

There are "several tests covering the penetration of brass on cast iron treated with Ferrofix and also untreated. This was done by the taking three test bars which had the upper surface smooth, one was left uncoated, one had one coat of Ferrofix applied, and the third had two coats of Ferrofix. They were then placed in the furnace and heated to the same temperature, and the surface coated with brass as in brazing. When cold the coated surface was planed 1/32 inch below the original surface. We found on the untreated piece no evidence of brass, while on the treated pieces brass was distinctly discernible in the pores of the iron. Another 1/32 inch was then taken from the two treated pieces, and we found on the bar that had a single coating of Ferrofix minute traces of brass, while on the double-coated piece the brass was very distinct. It must, therefore, be apparent that the joint we obtain is not simply a surface adhesion, but an actual anchoring of the filling material to the adjacent faces of the fracture."[1]

Tests Made by Riehle Bros.

Specimens 6″ x 6″ x 24″ long. Cast iron. Supports 20″ apart. Load applied at center of specimen.

Marked	Breaking strength in lbs.	After brazed
1	155,280	131,000
2	178,700	180,860
3	194,440	187,750
4	168,700	178,310
5	163,220	162,450

[1] Special information.

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Tests Made by Riehle Bros.

Marked	Area in sq. inches	Ultimate strain per sq. in. in lbs.	Remarks
No. 1. Brazed	.450	19,220	Broke outside weld
No. 2. "	.439	20,570	Broke outside weld
No. 3. Solid	.439	22,730	Broke

Two other tests by the same company showed increases of 1 and 6 per cent. for mended bars.

Of three tests by Lewis Foundry and Machine Co., the first showed an increase in strength of 1, and the other two a decrease of 14 and 29 per cent.

Two bars tests by Cramp's broke outside the joint.

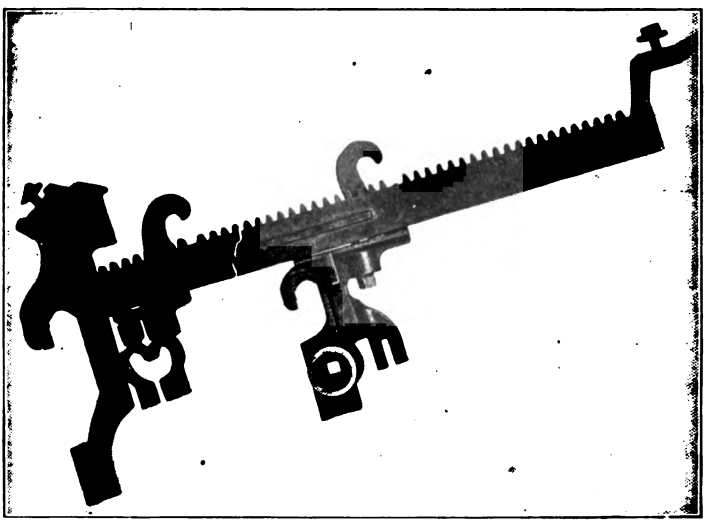

FIG. 88.—Broken arm that was made stronger than originally by the ferrofix brazing process.

The process is now used for all-sized repairs, small or very large.

"By accident a spoke was broken from a fly-wheel, 19 feet in diameter, 48 inches width of rim, weighing 21 tons. A new wheel would have cost $2700 and would have involved two or three months' delay. The Pich process was applied; the broken

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spoke was brazed into place, and $250 charged and paid for the job. The actual cost of doing this work was less than $50.[1]

Figure 88 shows a break of an important appliance that can be mended by this process.

BRAZING AND SOLDERING

Brazing and soldering are processes which are much like welding and which often shade over into welding. The brazing of brass is welding, except that the metal is not pounded together, but melted. The definitions for soldering and welding are given in the first chapter. Brazed and soldered joints resemble welded joints in as far as the solder and the metal of the piece or utensil amalgamate at the joint. But such joints are different from welded joints because the solder or spelter is of different composition from the metals it joins and serves the purpose of a go-between.

Brazing.—Iron, brass, copper, gold, and silver are the metals joined by brazing. The process is briefly: fluxing the metals at the joint, adding the brazing mixture called "spelter," heating until the spelter melts and works into the joint, finishing the brazed joint with the proper tools.

The flux used is either borax or boracic acid. The latter is used because it is cheaper; but for other than rough, commercial work borax is the btter. Borax should be burnt or calcined before using to drive off the water of crystallization. If this is not done, the borax will swell up under the flame, will blister, jump, and much of it be lost. Whereas calcined borax simply melts on the metal, runs over the surface in a thin glass, and cleans the surface of oxid and grease.

Before applying the flux, it is well to clean the metal with a file and remove all grease with a rag or alkali water.

Besides borax there are a number of other chemicals which can be used, such as zinc chlorid, sal ammoniac, common salt, and the corrosive acids. None of these are as good as borax. The first two are properly soldering fluxes, the third melts too readily, and the acids are liable to remain in the brazed joint and to decompose it slowly.

[1] *Proclamation of the Boston Society of Civil Engineers*, May 20, 1903.

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A number of patent powders and liquid fluxes are now on the market. They are mixtures of the common fluxes in such form that they can be easily applied to the work.

Spelter for brazing is used to cover a range of hard and soft alloys, though spelter is supposed to be a half-and-half alloy of copper and zinc. Hobart[1] gives the following table of brazing alloys:

Brazing alloys	Tin	Copper	Zinc	Antimony
Hardest	0	3	1	0
Hard (spelter)	0	1	1	0
Soft	1	4	3	0
Softest	2	0	0	1

English books mention spelter as composed of 1 part of fine brass, 1 part zinc—in other words, 2 parts zinc, 1 part copper. The hardest spelter will give the strongest joint, provided the spelter amalgamates perfectly at the joint. It will also require the hottest flame to melt and will be more difficult to handle. Softer spelters give softer joints, work in easier, and are cheaper to handle. Brass and iron joints that do not have to stand strain nor long time test are brazed with softer spelters. Spelter is powdered or filed into shavings, and mixed with the flux; or it is cut into thin strips or small chunks.

The torch, for brazing or soldering, is used when the work is not on a large piece or when a forge is not handy. A gasoline or kerosene torch can be used for small work. A blacksmith's forge is better, because the piece can be heated slowly and evenly, and cooled the same way. The same restrictions apply for all fuel used as apply for welding (see page 4). The fuel should be free from sulphur and soot and the flame should be non-oxidizing. In the case of coal and coke, do not let the fuel touch the parts to be brazed.

As in welding, a gas flame is the best. The operator can build up a furnace of fire-brick, with one or more nozzles of gas pipe

[1] "Brazing and Soldering," James F. Hobart, 1908.

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intruding. He can then regulate the size and direction of the flame, and heat and cool the work slowly and evenly.

Brazing work requires high temperatures: for iron it is done at a bright red, almost white, heat. This explains why the flame should be reducing and free from sulphur.

The gas flame varies from a blowpipe flame to that given by a two-way injector tube made of gas piping (see Fig. 89). The flame is a bunsen flame, with a blue cone.

To braze requires considerable variation in practice, according to the work at hand. Suppose the worker is about to braze

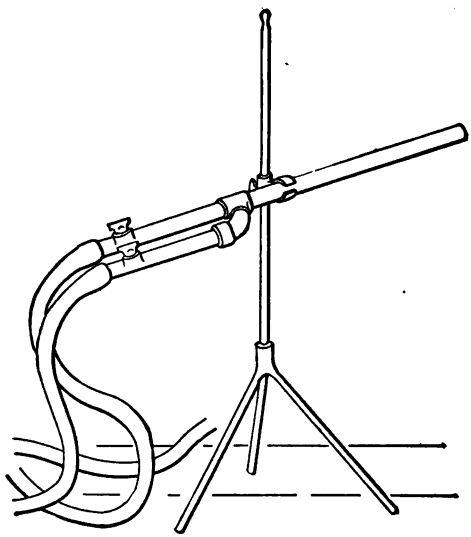

FIG. 89.—Air-gas torch for brazing.

together two cast-iron pieces of a fractured bar. He first cleans the ends of the bar at the fracture by filing and scraping away all grease and paint and then cleans the fracture with a wire brush. He then brushes the borax on the fresh surfaces or, in case a liquid preparation is used, he applies it with a brush. He then places the pieces together as he intends to braze them, resting them on fire-brick, and builds up a little oven of brick around and over the pieces, leaving one wall of the oven open for the flame (see Fig. 90). When brazing pieces or mending

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fractures, always press the surfaces as closely together as possible. No joint is too tight for the spelter to enter, while the tightest joint will be the strongest.

The burners are then brought up in front of the open oven and pointed at the work. These burners, for job work, are commonly made of two-way gas pipe with rubber hose for leading tubes. One tube carries the gas, the other the air blast. The air-blast tube is straight and draws in the gas by injection. The air blast is made by a motor-driven fan. For convenience these gas-pipe torches are swiveled on tripods. The air blast is started, the gas turned on, and the operator regulates the flame

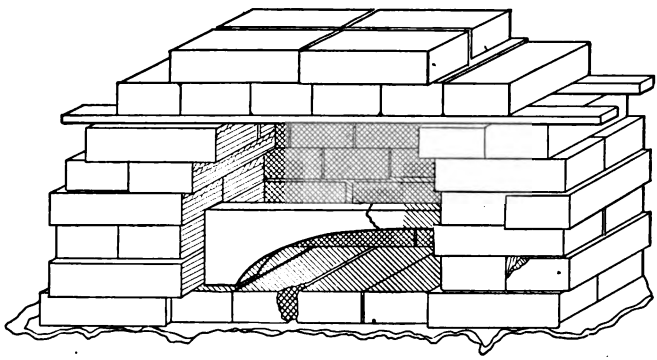

FIG. 90.—Makeshift brick furnace for brazing; showing broken casting in position.

to an even blue cone by turning the cocks. The flame is directed at the work and kept there until the brazing is done. At a bright red heat, the operator sprinkles more brazing powder or borax on the edges of the fracture, and works it back and forth with an iron spatula. This cleans the iron surfaces at the fracture, so that the spelter will *wet* the iron and run down into the fracture; next he shovels some spelter over the fracture and works it back and forth as it melts down. If the fluxing has been right, the spelter will slip down into the crack and fill up the entire fissure, *wetting* the iron surfaces, and the excess will run out of the lower crack of the fracture.

The operator now turns off the flame and allows the work to cool. Cast iron will cool quickly; but if the piece to be mended

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is at all intricate or has long arms, care must be taken to allow for equal cooling and shrinkage.

Care must be taken in heating the work to be brazed that the heating is done evenly and that no part is overheated. In the case of brass, overheating spoils the metal as it burns out the zinc to some extent. A safe method in brazing brass is to paint the piece over with a graphite preparation, except where the brazing is to be done. The graphite is indifferent to flame and flux and will prevent the zinc from volatilizing. One of the objections to soft spelter is the amount of zinc it contains.

In the making of a number of utensils brazing plays an important part. For this reason it is important to do the work quickly. Much *repeat* or stock brazing is now done by immersion, the same as iron is tinned. The pieces to be brazed are painted with graphite wherever necessary, are heated, and then plunged into a bath of melted spelter, on the top of which floats the melted flux. The flux cleans all of the metal unprotected by the paint, and then as the pieces are lowered further into the bath, the melted spelter readily wets the fluxed surfaces and brazes the pieces.

In brazing gold and silver, the alloy used is commonly a mixture of spelter with gold and silver; sometimes antimony, arsenic, etc., being added to reduce the melting point and to make the alloy fluid. This means that the process is really a soldering one. Brazing of gold and silver is a jeweler's art. It is done with small pieces and needs only a foot blast or a mouth blowpipe for the flame.

A brazed joint is commonly considered to be stronger than the adjacent metal. A brazed cast-iron piece will never fracture at the braze. Tests of well-brazed joints show them to to be from 10 to 25 per cent. stronger than the iron. A brazed joint is inferior in a number of ways to a welded joint. In the first place, the electrical conductivity is not equal to the piece brazed. Then there is the danger that free acid, pieces of flux or rust have been left in the joint and will lessen the strength at once or by slow action. Then, under water, a brazed joint may become an electric couple, and the metal may slowly disintegrate. Lastly, it is found that brazed joints will not stand concussion tests as well as welded joints. This is attributed to the

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presence of zinc, which is said to weaken the joint by its presence in the alloy.

Aside from these objections, a brazed joint is apt to be stronger than a weld, is generally cheaper, easier to make, takes less skill, apparatus, and time, and is often quite good enough for the purpose.

Soldering.—A solder is a metallic glue. There are almost an infinite number of solders, the most common being lead-tin solder for soldering the common commercial metals. The lead-tin proportion is varied to obtain solders with different melting points, strength, fluidity, and elasticity. Then other metals are added to the original lead-tin alloy, so that the properties of the solder are given a different range. The solder may be used for special metals and special purposes. Either the lead or tin or both may be dropped.

All solders have lower melting points than the metals they are intended to join; all solders must amalgamate with, or "wet," the metals they join. Most solders are weaker in tensile strength than the joined metals. For this reason soldered joints are not often intended to be specially strong. When metals are soldered in preference to being brazed or welded, it is because time and money can be saved and a satisfactory joint gotten.

Ordinary solder is half-tin half-lead, by weight. Hard solder is two parts lead to one part tin. Hard solder is more brittle, stronger, and has a higher melting point. On account of the present high price of tin, it is also cheaper. To ordinary solder, antimony is added to still further harden and stiffen the solder. Arsenic is sometimes added to make the melted solder flow freely. Bismuth and cadmium are sometimes added to bring the melting point down. For example, Wood's metal contains two tin, two lead, two cadmium, and eight bismuth, and melts at 70 deg. Cent. Bismuth is apt to make a solder brittle; while cadmium, like tin, helps to make the solder elastic or soft. Copper in small proportion will stiffen and strengthen solder, but it will raise the melting point sharply. Iron is seldom used in solders.

The data on the proportions of these metals in the solders is very inexact, and the exact properties of a given alloy are seldom

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known. The whole subject comes under the study of *alloys*, in which there is still much confusion and little accurate information. New alloys are being put on the market every day, some of them of known constitution, some unknown; many of them have properties claimed which they do not possess, and the practical men must find out for themselves which of the solder alloys are fit for the purposes they are advertised for. The future will see more accurate information at the call of the metal worker, who will be able to choose his solder with an eye to getting certain properties in the alloy and at the lowest cost.

The *soldering bit* is a copper-headed tool used to melt and manipulate the solder. The head is of various shapes, according to the work at hand, and is fairly bulky so that it will hold heat for a period of time (see Fig. 91). It is also pointed so as to be handy for working into seams and corners. The bit should be coated around the point with tin or the solder that is to be applied. This is so that when hot it will be coated with a skin of melted metal which will draw the solder with it. To *tin* the bit it is first filed or sand-papered free of scale, is fluxed with zinc chlorid, and then heated. It is then tinned by holding a tin stick against it and melting off some of the tin, which will adhere to the freshly fluxed surface. If the bit is at any time heated to redness while using, the tin will volatilize and the bit must be retinned.

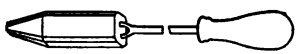

FIG. 91.—Ordinary soldering iron.

An ingenious soldering bit, or iron, recently patented, is described in the *Brass World* for February, 1905. The body of the bit contains a small reservoir in which is placed the solder. The reservoir has an opening near the head of the bit, which is opened by pressing a lever on the handle of the bit. The reservoir is so designed that the solder will not spill out while the workman is using it.

Fluxes for ordinary plumbing soldering are sal ammoniac, borax, resin in alcohol, tallow, or zinc chlorid solution. There are a number of patent or secret fluxes on the market, and many metal workers make their own special preparations. The soldering flux is generally applied before heating and after the metals

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have been cleaned. Its office is to combine chemically with any oxid left after the mechanical cleaning and also to dissolve any grease. A well-fluxed surface is made of raw metal, ready to be wet by the solder.

Sal ammoniac may be powdered on or applied with a brush as a solution in water. Calcined borax is powdered on or its solution painted on. Zinc chlorid is made by dissolving zinc to saturation in dilute hydrochloric acid. It is considered the best flux for plumbing.

Some solders are known as *self-fluxing*. They contain a metal which oxidizes when heated or which is a solvent for the oxid on the surface to be soldered. For example, Richards' aluminum solder is applied without flux. It contains phosphorus, which acts as a flux with oxid of aluminum. Self-fluxing solders should become popular in the future, when they are better known.

Soldering commonly requires much less heat than welding or brazing. The solders have melting points one-half to one-fourth as high, and the joints do not need to be annealed or cooled slowly. Hence a mouth blowpipe with a candle flame (Fig. 92) or a foot pump with a gas flame will give all the heat needed. In soldering large joints, where the heat is conducted away rapidly by the body of the metal, a gasoline or kerosene torch is used for preheating, and the solder is melted in a tinner's soldering furnace. For soldering jewelry and filigree an ordinary blowpipe is used. No special precaution need be taken with the flame, except to keep it hot enough to consume all of its carbon..

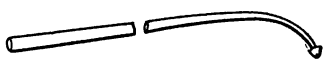

FIG. 92.—Ordinary mouth blowpipe.

I will not try to describe any special soldering process. There are too many metals that can be soldered, and too many ways to solder them, and too many special solders for a given joint. In general, the process of soldering includes: the mechanical cleaning of the surfaces of the metals to be soldered; the heating to a point where the solder will unite with the clean surfaces; the fluxing of the surfaces, before or after heating, so that the metal surfaces will be really clean; the application of the solder with the bit; and the finishing of the joint.

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In cleaning the metals, remove the rust and grease with a file, scraper, and a rag or alkali solution. If the flux is a liquid, it is best to first heat the metal a little and then paint on the liquid, which will eat away the oxid film, and will keep the clean surface covered until the solder is applied. If the flux is borax or resin in solution, first apply cold.

The solder is then melted on to the hot clean metal with a torch, or by pressing the hot bit against the solder stick and running it on to the metal. The bit is used to manipulate the solder over the surfaces and to give it the proper shape as it cools.

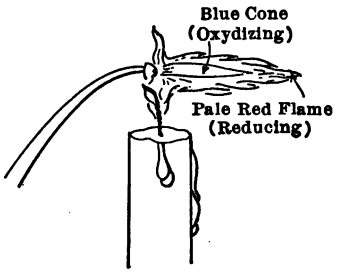

FIG. 93.—How to hold the blow-pipe in a candle flame.

Among the precautions necessary are to be sure the metals are clean wherever the solder is intended to bind. This can only be done by careful fluxing. Then the metals must be hot enough, but not too hot. If too hot, they will be liable to oxidize in spite of the flux, should the flux be prepared for a low temperature only. Also, if the metals are too hot, they will make the solder highly liquid. The bit must not be heated too strongly or the tinning will be driven off and the bit will then be no more capable of guiding and shaping the melted solder than would a stick of wood.

Many soldering runs, such as are found in the manufacture of fruit cans, are now done by automatic machinery; the cleaning, fluxing, and soldering being done in an endless chain, and the machine turning out the finished soldered job in a tenth the time it would take by hand, and making a neater, evener job. The soldering is done by dipping the fluxed metal in a bath of molten solder.

The following solders are used for lead, zinc, copper, brass, iron; and with the addition of cadmium or bismuth, for tin and britannia.

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Melting Points of Lead-Tin Solders[1]

Name	Lead	Tin	Melting point deg. Cent.
Tin	1	1	228
Soft solder	1	2	171
Medium	1	1	188
Hard solder	2	1	227
Lead	1	.....	320

For soldering gold, Gee[2] gives a table of solders with melting points of 983 deg. to 1020 deg. Cent. composed of about 1 part copper to 2 to 5 parts silver, and a small addition of zinc. In making up gold solders, it is quite as important to know what metals should *not* be used. Because gold is very easily ruined by certain metals, lead, tin, arsenic, and antimony should not be used in solders. Antimony is specially injurious, and bismuth in very small proportion will rob gold of its properties.

For silver the hardest solder is 4 parts silver to 1 part copper. A softer solder is 4 silver, 1 copper, and 1 zinc. About 5 per cent. tin makes a quick-running solder. Arsenic in varying amount is also added to soften the solder.

For platinum the solder was commonly gold of ordinary purity, melted on with a strong blowpipe. Since the introduction of the oxy-hydrogen flame, platinum is seldom soldered and almost all joints are welds.

Aluminum has been much experimented on recently (see page 21). There are a number of aluminum solders on the market. One of the best known, Richard's alloy, is composed of 22 tin, 11 zinc, 1 aluminum, 1 phosphor-tin. This is a self-fluxing alloy, due to the action of phosphorus on the aluminum oxid. Aluminum solders are pronounced in general to be unsatisfactory, because aluminum is electropositive to all other metals, and electrolytic action of a destructive nature is apt to set in some time after the joint is made, especially if the joint is exposed to water. Tin is harmful to aluminum and should not be used in its solders. It is claimed that tin will permeate into the aluminum in time and make it rotten and brittle.

[1] *Brass World*, Nov., 1905.
[2] "The Goldsmith's Handbook," Geo. E. Gee, 1903.

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GLOSSARY OF TERMS

Burnt Metal.—If iron or steel is heated to bright white, it will crystallize when cooled. This will make it brittle, and makes the wrongly called *burnt iron.* To prevent this brittleness the metal must be worked or hammered when cooling. Steel especially is easily *burnt* because its carbon is apt to crystallize with the iron to form brittle alloys, above bright red heat.

Chamfer.—To bevel the edge of a sheet or bar of iron so that it will be the proper shape for welding.

Cold-short.—When a metal is brittle below incandescence. Generally caused by an impurity, as 1 per cent. of phosphorus in iron. Pure zinc is *cold-short* at about 260 deg. Cent.; aluminum above 600 deg. Cent. The latter may be said to be *hot-short,* but not *red-short.*

Critical Temperature.—Used to designate the temperature at which the metal itself or any important constituent begins to crystallize. The more sharply defined are the critical temperatures, the less weldable is the metal, as high-carbon steel.

Ferrite.—The mineralogical name for pure iron, to distinguish from martensite, cementite, etc., which are terms for the iron-carbon series.

Flux.—Any substance, compound, or mixture used to clean the surface of the substances to be welded or soldered. The flux must be chemically or physically active toward the surface impurities, but not toward the substances to be joined. Sand is a flux for iron, as it forms a fusible silicate with the iron scale, but has no affinity for the iron. Zinc chlorid is a flux for lead, zinc, copper, etc., to be soldered, as it dissolves the surface oxids, leaving a clean surface.

High-carbon Steel.—A general term for a hard, brittle steel. The carbon content is about 0.50 per cent. or more.

Oxidizing Flame.—A flame is commonly caused by the chemical union of oxygen with another substance. If the flame has more oxygen supplied it than is needed for perfect combustion, the free oxygen in excess makes it an oxidizing flame—one that rusts or burns the metal. A flame may be oxidizing in one place and reducing in another.

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Red-short.—When a metal becomes brittle at a red heat, it is said to be *red-short.* Generally caused by an impurity, as 1-per cent. of sulphur in iron, or a minute quantity of bismuth in lead or gold.

Reducing Flame.—A flame in which the fuel is in excess of the oxygen necessary for perfect combustion. The tendency of such a flame is to draw some oxygen from the burned parts of the metal. At all events it prevents burning within its radius.

Spelter.—Now used in commerce as the name for pure zinc. Spelter is also the name for half-and-half brass used for brazing. The best way to use this term is not to use it at all.

Swage.—A shaping tool, used in finishing a weld.

Upset.—To enlarge the metal pieces at the place where they are to be welded. The enlargement at the welded joint is called the upset.

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